CONSTRUCTION INDUSTRY INSTITUTE - HONG KONG

AND

THE HONG KONG POLYTECHNIC UNIVERSITY

Draft Final Report of the CII-HK

Research Project

Entitled

Developing a prototype for a Rapid Demountable Platform (RDP) - Stage 2 of Construction Safety Involving Working at Height for Residential Building Repair and Maintenance

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September 2007

ACKNOWLEDGEMENTS

The Construction Safety Research Team of the Department of Building and Real Estate, The Hong Kong Polytechnic University (PolyU) would like to thank the Construction Industry Institute, Hong Kong (CII-HK) and PolyU for jointly providing financial support to this research study. The project involved a research team of 13 members from PolyU, which was facilitated by a group of Task Force members.

The Research Team would like to express sincere thanks to task force members for their generous assistance in this project. Below are the lists of members:

Task Force members	Organization
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3. Mr. K.L. Pang	Labour Department
4. Mr. W.S. Tang	Occupational Safety and Health Council
5. Mr. Conrad Wong	Yau Lee Construction Co. Ltd.
6. Dr. Nicolas Yeung	Construction Industry Institute (Hong Kong) Ltd.
7. Mr. Augustine Chow	Hong Kong Housing Society
8. Mr. M.T. Kan	Hong Kong Construction Industry Employees General Union
9. Mr. Alkin Kwong	The Hong Kong Association of Property Management Co. Ltd.
10. Mr. Francis So	Wui Loong Scaffolding Works Co. Ltd.

Heartfelt thanks are also given to Sun Hung Kai Properties Ltd. for the kind offer to visit their research on temporary working platform and sharing valuable experience with the research team.

Special thanks would also be extended to the Hong Kong Construction Industry Employees General Union and the Hong Kong General Building Contractors Association for their grateful help and participation in the focus group workshop.

Finally, interviews could not be carried out so successfully without the support of the Occupational Safety and Health Council (OSHC) and Buildings Department (BD). Their time spent is very much appreciated.

EXECUTIVE SUMMARY

Prevention of fall from height accidents has long been a hot topic in the field of construction safety. Previous research has indicated one of the potential hazards was induced from the use of steel bracket as scaffold support. While researchers are focusing to improve the existing scaffolding system, this research introduces a newly developed device to minimize fall accidents. The working platform, namely Rapid Demountable Platform (RDP) is applicable over the window frame without fixing by anchor bolt. Emphasizing on the rapid installation/dismantling, RDP provides another safer option for working at height. The development of Prototype I has given an insight for the industry and practitioners urging for further improvement. Focusing on the fabrication materials and the application flexibility, a more advanced RDP Prototype II has been produced. The input of modular concept and aesthetic factor has been incorporated in the design aspect, achieving a more user-friendly platform. Its structure has further been verified by computer modeling technique and laboratory testing. With the mockup of RDP Prototype II fabricated, the provision of user manual and training guide has given comprehensive instructions for the end-users.

The aim of this project was to refine the RDP Prototype I based on sound engineering design, user friendliness concept and aesthetics. The process of refinement has undergone several stages. The generation of idea was firstly inspired through comments from practitioners, task force members and in-house team members. Consolidated suggestions were deliberated by the Research Team members which composed of designers, structural engineers, production engineers, and project engineers. Liaison between designers and engineers went on whenever technical difficulties encountered. Finally, the feasibility of usage in actual environment was examined under relevant testing.

The complexity of this project meant that the Research Team was split in to three sub-teams, so that the expertise of the team members could be drawn to their maximum potential. These teams included the Design Team (design engineers and industrial designers), the Structural Design (Testing) Team (structural and production engineers) and the Implementation Team (project engineers). The Design Team was responsible for considering the “function” and “form” of the RDP. The team needed to consider: how workers — users — interact with the RDP; how the RDP would meet the defined function, in particular safety considerations, and needs and preferences of workers; how the RDP could be designed so that it would be easily manufactured and fabricated at the site; how the RDP could give physical and psychological evidence to workers to adopt it regarding the functional and product semantical aspects etc. The Design Team contained design experts with experience in handling the design of industrial products, and also worked together with the other sub-teams to deliver the design. The Structural Design (Testing) Team was responsible for testing the RDP in a laboratory environment according to international standards to ensure that it would be safe and reliable to use. Besides, the team also advised the Design Team on the structural stability and strength of certain components and materials that could be used. Last but not least, the Implementation Team was primarily responsible for commissioning and implementing the RDP system by organizing demonstration sessions, focus group workshops and face-to-face interviews with senior industrial practitioners and front-line workers to gather ideas and comments from external sources to support the other two sub-teams. Views and ideas were gained from related government departments, private companies and front-line workers. The Implementation Team was also responsible for documenting the installation and dismantling procedures of the RDP.

The production of the RDP Prototype II is the joint efforts of three separate and yet closely related teams. There are several differences between RDP Prototype I and II. Firstly, the standing panels for Prototype II were made of steel panels with sinkholes instead of hardwood. The U-Frame utilized 50×30×3mm steel RHS and the triangular frame utilized 25×25×2.5mm steel SHS of Grade S355, instead of Steel SHS in 40×40×3mm Grade 43. The railings in Prototype II were made of aluminum pipes rather than galvanized iron pipes. The toe-boards utilized aluminum sheets rather than hardwood. In Prototype II a modular concept was incorporated for the standing panels and railings in unit dimensions. Product semantics was also applied by the toe-boards and base support in yellow stripes. The standing boards changed from 3 rectangular planks in longitudinal direction in the Prototype I, to 3 square sheets in transverse direction. The interlocking system adopted a pair of C-ring with screw attached rather than fixing by pins. And finally the RDP was improved in Prototype II by a weight reduction of 15% (14 kg) and an installation time of 33% (5 minutes less).

The RDP is not intended to totally replace the traditional bamboo truss-out scaffold. Instead the RDP is designed to act as an alternative or a supplement to the bamboo truss-out scaffold. It is hoped that the RDP could help to minimize fall from height accidents especially in cities similar to Hong Kong where working at height is frequently encountered.

Brief Biography of The Hong Kong Polytechnic University Construction Safety Research Team

Professor Albert Chan, *MSc (Aston), PhD (S. Aust.), FCIOB, FAIB, FHKICM, FHKIE, MAIPM, MIEAust, AAIQS, MRICS, RPE(Bldg),* had 5 years hands-on experience in the field of construction project management before changing to an academic career in 1987. He is a Chartered Builder, Engineer, Project Manager, and Surveyor by profession. Prof. Chan has worked in a number of tertiary institutions both in Hong Kong and overseas, including City Polytechnic, the predecessor of the City University of Hong Kong, the University of South Australia, the Queensland University of Technology, the Bond University, and The Hong Kong Polytechnic University. He has been commissioned by a number of organisations to provide consultancy services in project management and construction economics. Prof. Chan holds an MSc in Construction Management and Economics at the University of Aston in Birmingham, and a PhD in Project Management at the University of South Australia. He is currently Associate Head of the Department, an Adjunct Professor of the Queensland University of Technology; the Bond University, Australia and the University of South Australia; and a Founding Director of the Construction Industry Institute, Hong Kong. His current research interests are in construction industry development, construction safety, and project procurement.

Professor Francis Wong, *BSc(Hons), MSc, PhD, FCIOB, FHKIE, FHKICM, RPE(Bldg), MRICS, MCIArb, MCMI, MIOSH*, obtained his BSc (Hons) in Building Degree from the then Brighton Polytechnic in the U.K. He worked for a building contractor in Hong Kong in 1980 and the Mass Transit Railway Corporation two years after. In 1984, he joined the Department. In 1988, he completed his Master's Degree at the University of London, majored in building economics and management. He completed his PhD Degree at the South Bank University in England in 2000 on 'Construction Safety in Hong Kong'. He is currently Head of the Department and the Director of the Research Centre for Construction and Real Estate Economics. In terms of community and professional services, he was the Senior Vice-Chairman of the Chartered Institute of Building (HK Branch) in year 1994/95. Chairman of the Safety Specialist Group of the Hong Kong Institution of Engineers (HKIE) in Year 1999/2000, and Vice-chairman of the Construction Safety and Health Committee of the Occupational Safety and Health Council in Hong Kong from 2001 to 2004.

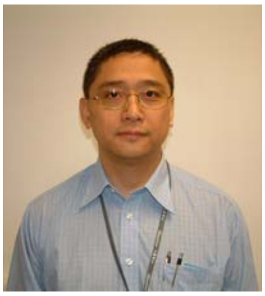
Dr. Michael Yam, *BSc, MSc, PhD, MASCE, MIEAust, CPEng, MIPENZ, PEng, MHKIE*, obtained his BSc. in Civil Engineering with Distinction and MSc. at the University of Alberta, Canada and completed his PhD degree at the same University in 1994. He subsequently was appointed as a research engineer at the University before returning to Asia in 1995. Prior to joining the Department of Building and Real Estate in early 2002, Michael has spent several years with the University of Macau as Assistant Professor of Civil Engineering, as well as the Hong Kong Technical College as Lecturer. He has also obtained consultancy experience in the areas of the design and construction of both reinforced concrete buildings and structural steelworks in Hong Kong. Michael is a member of the Hong Kong Institution of Engineers, Institution of Professional Engineers New Zealand, Institution of Engineers, Australia and the American Society of Civil Engineers.

Dr. K W Michael Siu, *BA(Hons), MSc, MA, MEd, FCP, PhD, FCSD, FRSA, FRSH, FRGS, FCollP, RPE (MIE), CEng, MIEE/MIET, MIED, MHKIE, MHKCS, MHKDA*, is Public Design Lab Leader of the School of Design at The Hong Kong Polytechnic University. He has been a visiting professor at universities in China and South Korea. He was the ASIA Fellow/Visiting Scholar at the NUS (2006-2007), Fulbright Scholar at MIT (2002-2003), Visiting Scholar in the Engineering Design Centre of the University of Cambridge (2001) and Beijing Institute of Technology (2000). He has been invited to be the Visiting Scholar of the UC Berkeley to carry out his research on public design for densely populated urban areas (2007-2008). His research and design focus is on both technological and social perspectives. He has been involved in a number of funded research and design projects related to public environment and facilities. He owns more than 40 design patents in the United States, PRC and other Asian countries.

Dr. Daniel Chan, *BEng(Hons), PhD, MAPM, MHKICM, MASCE, ICIOB, AMAIB*, is currently an Assistant Professor in Construction Management and Engineering at the Department of Building and Real Estate, The Hong Kong Polytechnic University. He is a project manager and construction manager by profession. He obtained his BEng(Hons) degree in Civil and Structural Engineering and PhD degree in Construction Project Management, from the Department of Civil Engineering, The University of Hong Kong. Upon graduation, he started his engineering profession as an Assistant Structural Engineer by joining a local leading building design consulting engineering practice. He joined PolyU as a Postdoctoral Research Fellow at the Department of Building and Real Estate in Mid-April 2001. He has published several research papers on the broad theme of project management in refereed academic journals and international conference proceedings. His current research interests include construction procurement systems, project partnering and strategic alliancing, construction safety management, public private partnership and target cost contracting. Furthermore, Dr. Chan has been appointed as the Editor of the CII-HK Newsletter "*The Innovator*" and a Member of the CII-HK Editorial Board since July 2003. He has also served on the Committee of the Association for Project Management (Hong Kong Branch) responsible for membership recruitment and university education since November 2005.

Ir Albert Kwok, *MSc (Civil), CEng, MHKIE, RPE(Civil & Structural), MICE, MIStructE, CMIOSH, Registered Safety Officer*, had 12 years working experience in the field of construction work in civil and structural engineering, engaged in a number of housing, footbridges and highways projects before joining The Hong Kong Polytechnic University. He is a Senior Engineer in the Industrial Centre (IC) of the University responsible for planning and administration of IC training programmes for construction students of the University and the sister institutions. He is one of the key teaching staff in subjects of construction safety and safety management in safety programmes offered by IC. Ir Kwok holds a MSc in Civil Engineering at The Hong Kong Polytechnic University and is a Chartered Civil and Structural Engineer by profession, he served in the Safety Specialist Committee of the Hong Kong Institution of Engineers from 1998 to 2005 and has been the HKIE's representative in Board of Studies of CITA safety Courses for two years. His research interests and consultancy work are mainly in areas of construction safety and safety management.

Mr. Wai-Che Lee, *BSc, GDAS(OHS), AppSc(SafMgt),MCIOB, CMIOSH, P.Eng(UK) FSPE, MAIC, Registered Safety Officer,*
he is an Associate Engineer in the Industrial Centre (IC) of the Hong Kong Polytechnic University and had 26 years of experience in higher education and training relating to construction technology and construction safety. He is one of the key teaching staff in subjects of construction safety and safety management in safety programmes offered by IC.



Mr. Pete CW Wong, BSc(Hons), Post Grad. Cert., MSc had 10 years experience in the field of quality assurance and reliability engineering in manufacturing sector and more than 15 years experience in project management and training in project planning. He is currently a Technical Officer of the Industrial Centre (IC) of The Hong Kong Polytechnic University responsible for co-ordination of industrial projects undertaken by the Centre which include research projects in the University, students' projects of different Faculties and projects initiated by the local industrial sectors.

Dr. Chun-Ho Liu, *BEng (Hons), PhD,* is Assistant Professor with the Department of Mechanical Engineering, The University of Hong Kong. He received his BEng and PhD degrees from the Department of Mechanical Engineering, The University of Hong Kong. Dr. Liu stayed at the Department as a Research Associate in 1999. Afterward, He joined the Atmospheric Chemistry Division, National Center for Atmospheric Research, USA as a Postdoctoral Research Fellow to further his research career. He returned to Hong Kong and joined BUDA Engineers & Consultants Limited as a Senior Engineer in 2002. Dr. Liu resumed his Research Associate position with the University of Hong Kong in 2003 before he joined the Department of Building and Real Estate, The Hong Kong Polytechnic University in 2006 to 2007. His research interest lies in the areas of building-, micro-, and city-scale ventilation, and air pollution physics and chemistry.

Dr. Edmond Lam, *BSc, PhD,* obtained his BSc(Hons) degree in Construction Economics and Management with commendation (First in Class). After graduation, Edmond worked in a construction cost consultancy firm in Hong Kong as Assistant Quantity Surveyor and later joined the University again where he obtained his PhD degree in Construction Procurement Management. He is currently a Post-doctoral Fellow in Construction Management at the Department of Building and Real Estate, The Hong Kong Polytechnic University. Dr. Lam has published several research papers on the theme of construction procurement management in refereed academic journals and international conference proceedings.

Mr. Paul Lo, *BSc(Hons), MDesAP* was major in BSc (Hons) Product Design with Analysis and Master of Design in Advance Practices in Department of Mechanical Engineering and School of Design, The Hong Kong Polytechnic University respectively. Currently, he is Research Assistant and Member of Public Design Lab of the School of Design. His research focus is on street furniture and public facility design.

Dr. Esther Choy, *BEng(Hons), MPhil, PhD,* Dr. Esther Choy obtained her BEng(Hons) degree in Environmental Engineering at The Hong Kong Polytechnic University. She further studied for an MPhil degree in the same University. After several years of working in research related to wastewater technology, she obtained the PhD in the field of Environmental Engineering. She is currently a Research Associate conducting a project on “Pay for Safety Scheme for Sub-contractor” in the Department of Building and Real Estate at the Hong Kong Polytechnic University.

Miss Tracy Chung, *BEng(Hons),* Miss Tracy Chung obtained her BEng (Hons) degree in Civil and Structural Engineering at The Hong Kong Polytechnic University. After several years of working in construction industry, she further studied an PHD degree in Civil and Structural Engineering in the same university. The research topic was about strengthening of existing structures against seismicity by using energy dissipation system. She was a Research Assistant at the Department of Building and Real Estate of the Hong Kong Polytechnic University. She was responsible for structural analysis and laboratory works of this project. She is currently working in a structural consultancy firm in Hong Kong.

Miss Esther Cheung, *BEng(Hons), MPhil*, Miss Esther Cheung obtained her BEng (Hons) degree in Environmental Engineering at The University of Nottingham in England. After several years of working in waste management research, she further studied an MPhil degree looking at the photocatalytic behaviour of recycled products. She successfully obtained her MPhil degree from the Department of Civil Engineering at The Hong Kong Polytechnic University. She is currently a Research Associate and has been working on a construction safety project and a public private partnership project for the Department of Building and Real Estate at the Hong Kong Polytechnic University. At the same time she is registered as a PhD student looking at public private partnerships, in the School of Built Environment at Queensland University of Technology in Australia.

TABLE OF CONTENTS

Chapter 3 Research Methodology Adopted to Develop RDP Prototype II

Chapter 4 Implementation Team

Chapter 5 Design Team

Chapter 6 Structural Design (Testing) Team

List of Tables

List of Figures

Chapter 1 — Introduction

1.1 Background

The ageing of buildings in Hong Kong has become an alarming concern for the government and the general public recently. In order to manage the residential buildings in good condition, there is an increasing demand on repair and proper maintenance of existing housing stocks. The Hong Kong's construction industry has shown significant improvement in safety performance recently. The number of industrial accidents in the construction industry has decreased from 11,925 in 2000 to 3,499 in 2006, which is an encouraging drop over 70%. However, fall of person from height has always represented a large proportion of the fatal accidents. In 2004, fall of person from height represented half of the total number of fatal accidents in the construction industry (Labour Department, 2007). In Hong Kong, residential building repair and maintenance works very much rely on the bamboo truss-out scaffold supported by steel brackets. Due to height and the existing conditions of the high-rise buildings, external wall repair and maintenance works are extremely difficult. For example, it would be impractical to use scaffolding towers or equivalent devices which need to be erected from the ground, to reach a flat say on the 28th floor, for a small job such as changing an air conditioner. However, a lot of fall from height accidents are related to the use of the bamboo truss-out scaffold / bamboo scaffold as shown in Table 1.1.

Table 1.1: Summary of recent fall from height accidents related to the use of the bamboo truss-out scaffold.

Case No.	Date	Accident Summary	Source
1	02/12/06	A bamboo scaffold with eight workers collapsed. One of the workers fell to the ground floor and died. Three of the workers fell to the 3rd floor. And the remaining four workers escaped by themselves.	Apple Daily Newspaper (2006)
2	2005	A worker was carrying out maintenance work to the external wall of a building at 7th floor. He climbed on to the bamboo scaffold outside not wearing a safety belt. When climbing to the bamboo scaffold, he slipped and fell to death.	Ming Pao Newspaper (2005)
3	2005	Two men had not been wearing safety belts while working outside the window of a fifth-floor unit in an industrial building. After the truss-out scaffolding they were working on collapsed, they died.	Oriental Daily Newspaper (2005)
4	06/01/07	A worker was painting the window frame of a house whilst he fell 5m to his death. It was suspected that the worker may not have been wearing a safety belt.	Sing Tao Newspaper (2007)

The current practice for doing external maintenance work in Hong Kong is to erect a temporary platform by way of a bamboo truss-out scaffold supported by steel brackets. However, the practice appears to be highly unreliable and a number of fatal accidents have occurred. Between 2000 and 2004, there were four fatal fall accidents in repair and maintenance works amongst 22 fatal cases that involved the use of bamboo truss-out scaffold (CII-HK, 2007). The number of fatal accidents associated with the bamboo truss-out scaffold has shown that this practice is highly unreliable. Problems identified in this system include lack of standardized brackets, unpredictable wall conditions, improper installation, low quality anchor bolts, lack of personal protective equipment etc.

1.2 Recent Advancements on Construction Safety Involving Working at Height

Construction safety is not only the concern of researchers in the academic field; however, practitioners from the government and the industry have also put much effort in improving safety performance of working at height for residential building repair and maintenance works. The Labour Department of the HKSAR has stipulated various ordinances, regulations, guidelines and safety procedures for maintaining construction safety. Statutory provisions on the prevention of fall of person from height are set out mostly under the Factories & Industrial Undertakings (F&IU) Ordinance and its subsidiary regulations, as well as under the Occupational Safety and Health Ordinance. The Accident Analysis and Information Division of the Labour Department recently produced a report entitled ‘Accidents in the Construction Industry of Hong Kong (2000-2004)’ to identify the category, trend and causes of fall of persons on building repair and maintenance works. The Labour Department and the Occupational Safety and Health Council have also produced many safety work guidelines related to fall prevention, fall identification and fall minimization. These documents have adapted international best practices and combined them with the local context to derive suitable guidelines for Hong Kong. With a view to tackling malpractice in the use of ladders, the Hong Kong Architectural Services Department produced key notes on enhanced measure for safe use of ladders. Internationally, the Work at Height Regulations 2005 of U.K. have just been in force in April 2005 for proper implementation of working at height. Some property management companies in Hong Kong have set out working at height guidelines, safety handbook and working at height instructions for workers to follow.

In Hong Kong, residential building repair and maintenance works rely heavily on the use of bamboo truss-out scaffold supported by steel brackets. However, the current practice of erecting a temporary platform by way of a bamboo truss-out scaffold supported by steel brackets is considered as highly unreliable and a number of fatal accidents have occurred. To provide local contractors with a suitable anchor point, a temporary transportable anchor device was devised and manufactured in the U.S. and the U.K. The Labour Department and the Occupational Safety and Health Council jointly launched such devices for use by maintenance contractors through a sponsorship scheme. In the private sector one of the largest property developers in Hong Kong produced a report to prevent accidents with bamboo truss-out scaffolds in 2005. Another leading scaffolding specialist has recently introduced a computerized climbing scaffold system to the local market.

1.3 Engineering Solution

To address these problems associated with the bamboo truss-out scaffold, a temporary working platform namely the ‘Rapid Demountable Platform (RDP)’ was designed as an alternative. The RDP Prototype I was designed to provide a rapid, demountable temporary working platform for inspection, repair and maintenance works on external wall of buildings.

The RDP Prototype I was designed to be hung over the building wall and eliminate the use of anchor bolts. RDP Prototype I was constructed with demountable panels and supported by two supporting frame units and two triangular frame units, each pair of these units held the platform on either side. The supporting frames hung over the building walls. And the triangular frames were slotted into the supporting frames to hold RDP Prototype I. The frames could be adjustable to suit walls of different heights and thicknesses. RDP Prototype I also had railings and toe-boards to prevent the user from falling out. The materials used were existing materials in the laboratory including mainly of steel and wood. The design for RDP Prototype I has already obtained a patent application number from the People’s Republic of China Patent Office (200610009426.9, commencement date 22/02/06, Figure 1.1).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发文日期
2006年3月8日

申请号：200610009426.9

专利申请受理通知书

根据专利法第二十八条及其实施细则第三十九条、第四十条的规定，申请人提出的专利申请国家知识产权局予以受理。现将确定的申请号和申请日通知如下：

申请号： 200610009426.9
申请日： 2006年2月22日
申请人： 香港理工大学

发明名称： 快速可拆卸平台

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Figure 1.1: Patent Obtained for the RDP Prototype I.

The RDP Prototype I was designed to address the previously mentioned problems by eliminating the need to install steel brackets. The special features of the concept lie in the fact that it can be mounted from inside of the building and no anchor bolts are required to be installed on the external walls (hence reduce the risk of falling). The RDP Prototype I can be easily installed / dismantled by a trained worker in a short period of time making it handy to use. In addition, the RDP Prototype I will not require any consumable items (as compared to the conventional bamboo truss-out systems which require anchor bolts and bamboos). The RDP Prototype I presented only an initial concept, further study was required to perfect the design and test for its ability to withstand load. Therefore, this research study presents RDP Prototype II which was designed to address some of these unsolved problems.

1.4 Possible Applications

The RDP provides a safe, fast and easy install/dismantle temporary working platform for general external building inspection, repair and maintenance works.

The RDP is feasible in applying on small-scale maintenance works, as proposed below:

- External building inspection
- Temporary working platform for installing bamboo truss-out scaffold (alternative)
- Change of air-conditioning unit
- Maintenance on plumbing/drainage system
- Painting
- Plastering
- Tiling/rendering

Old residential buildings in urban area are suitable for the erection of RDP. Typical examples have been captured in Figure 1.1. The RDP could rest on the window frame without the hindrance of window bay.

Figure 1.2: Typical Examples of Old Residential Buildings in Urban Areas of Hong Kong.

1.5 Aims and Objectives of the Study

The aim of this study is to develop the RDP Prototype II based on the initial RDP Prototype I. The new version will solve the limitations and disadvantages of the first version to ensure that it is a safe, reliable and user-friendly product. It is hoped that the RDP Prototype II will be an alternative or a supplement to the traditional bamboo truss-out scaffold. The objectives include:

- To refine the RDP Prototype I.
- To develop RDP Prototype II using alternative materials to Prototype I.
- To analyse whether the prototypes are durable and safe to be used for external building inspection, repair and maintenance works.
- To investigate the acceptability and practicability of the prototypes by various parties.
- To suggest the most suitable design for the final prototype.

1.6 Structure of the Report

Chapter 1 gives an introduction to this research study. By looking at the current status of safety when working externally at height in construction repair and maintenance works, reasons for conducting this research project are explained. This chapter will also summarize the contents of this report.

Chapter 2 presents part of the results delivered in Stage I of this research topic. As part of the Stage I deliverables the RDP Prototype I was designed. This chapter will review the design and summarize findings from a questionnaire survey conducted to collect comments and recommendations from professionals in the construction industry.

Chapter 3 looks at the research methodology adopted for this research study. The chapter will outline the work load distribution and organization of the research team, and also describe the responsibilities of each of the three sub-teams (Implementation Team, Structural Design (Testing) Team and Design Team). Also, this chapter will describe the methods used to achieve and collect the necessary data to facilitate the refinement of the RDP.

Chapter 4 looks at the work conducted by the Implementation Team in order to support the other two sub-teams. In order to gain a perspective of what the industry wants a questionnaire survey, demonstration and focus group workshop with front-line workers were conducted by the Team. The results that were adopted to facilitate the design of the RDP Prototype are presented. In addition the Implementation Team studied the options that are available if the product is launched to the market, and by interviews with several Government Works Department, highlighted the administrative obstacles that could be faced. Finally the Implementation Team presents the RDP installation procedures for the RDP Prototype II.

Chapter 5 presents the design considerations and work conducted by the Design Team in order to develop the RDP Prototype II. Their design approach and coordination with the other sub-teams are described in detail.

Chapter 6 looks at the work conducted by the Structural Design (Testing) Team. The chapter looks at an overview of the structural design procedures and criteria that were required in order to test both the RDP Prototypes. The laboratory tests and numerical analysis that were conducted are also reported. And finally, the results on the structural stability are discussed.

To conclude, Chapter 7 will wrap up the project by reviewing the project objectives and the major findings from this research study. In addition, there will be a comparison of RDP Prototypes I and II and recommendations based on these two prototypes. Lastly the chapter will recommend possible areas for future research.

1.7 Limitations of RDP Prototype I

The RDP Prototype I was developed in a previous research project looking at fall from height accidents during repair and maintenance works. As the Prototype was not part of the outputs for the previous project the extra resources were not encountered for. Due to this limitation there were a number of problems with the Prototype. The RDP Prototype I was only an initial design. There was a need for it to be further developed and its reliability to be tested. In addition, the production of RDP Prototype I was limited to the available laboratory resources and materials only, therefore the choice of materials should be investigated. Comprehensive laboratory testing was also required to analyze the durability, practicability, acceptability and safeness of the RDP Prototype.

1.8 Summary

Hong Kong faces an increasing number of fatal construction fall accidents especially in the repair and maintenance sector. The traditional method of using the bamboo truss-out scaffold for these works has proved to be unreliable and insufficient. This research project presents an initial concept of a temporary working platform which aims to provide an alternative or substitute to traditional practices. Therefore the further development and testing of this prototype would be beneficial to the construction industry at whole.

Chapter 2 — Development of RDP Prototype I

2.1 Introduction

The first stage of this research project has developed some new ideas, inventions and alternatives to improving construction safety involving working at height for residential building repair and maintenance works. One of the main achievements was the development of a RDP Prototype. The RDP Prototype I was designed using steel to replace the truss-out bamboo scaffold supported by steel brackets which appears to be highly unreliable and a number of fatal accidents have occurred. The invented system addresses many of the problems relating to the truss-out scaffold by eliminating the need to install steel brackets. The special features of the invented system lie in the fact that it can be mounted from inside of the building and no anchor bolts are required to be installed on the external walls. Besides, the system can be installed / dismantled by a worker in less than 15 minutes and is therefore extremely handy. In addition, the system does not require any consumable items (as compared to the conventional truss-out systems which require anchor bolts and bamboos). It is believed that the system is able to help reduce the number of construction fall accidents in Hong Kong.

2.2 Findings on Prototype I

As mentioned in Chapter 1 of this report the design of RDP Prototype I was patented at the Patent Office of the People's Republic of China. Figure 2.1 shows some illustrations of the RDP Prototype I which were extracted from the patent. Figure 2.1a shows the RDP Prototype I as if it was clamped to a wall in a practical situation, and Figure 2.1 b shows the fully installed RDP Prototype I with dimensions in mm.

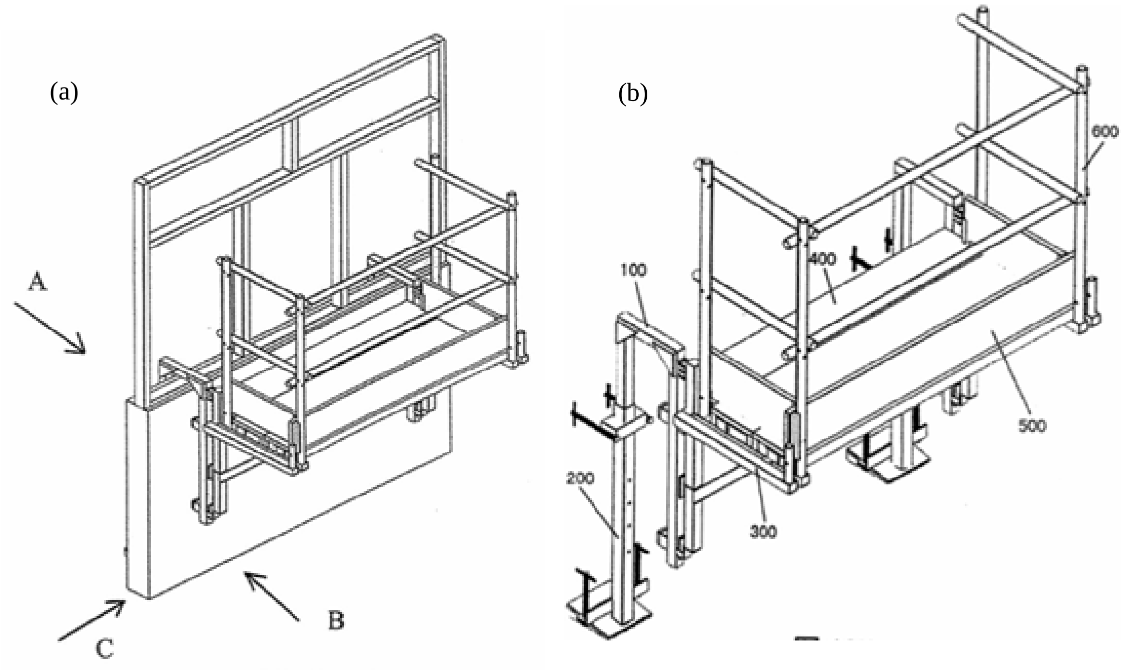


Figure 2.1: RDP Prototype I (a) Clamped to Wall and (b) Fully Installed (Illustrations of RDP Prototype I Extracted from the Patent.).

In order to achieve a realistic impression of the design of the RDP Prototype I, a mock-up was manufactured in the Industrial Centre of The Hong Kong Polytechnic University. Figure 2.2 shows photographs of the mock-up. Figure 2.2a shows a photograph of the mock-up's front view, whereas Figure 2.2b shows a side view of the mock-up.

Figure 2.2: The Mock-up of RDP Prototype I, Photos Taken (a) at Front View and (b) at Side View Respectively.

The RDP Prototype I was manufactured using readily available materials in the laboratory. Materials included mainly of steel and wood. There were four major units that complete the RDP Prototype I, namely:

1. Supporting Frame Unit (SFU);
2. Triangular Frame Unit (TFU);
3. Platform Panels Unit (PPU) and,
4. Railings and Toe- boards Unit (RTU).

The SFU and TFU were used to support the platforms on either side, these were manufactured using Steel SHS of 40×40×3mm. There were three PPUs made using wooden planks which rested on the TFUs. The ten railings (six horizontal and four vertical on the sides and front) used galvanized iron pipes and were connected using pins which were attached by chains to avoid lose parts. The three toe boards (one on each side and one on the front) were made using hardwood. The total weight of the RDP Prototype I was 95 kg. The heaviest components were the SFUs and TFUs.

A simple installation procedure of the RDP Prototype I was included in the patent, the details are as follows:

1. Set up the SFU to the parapet wall through the window frame. The SFU can be adjusted to appropriate height. Gently tighten the screws on the SFU to bear against the wall.
2. Install the TFU to the SFU at the desired level. Insert the anchor pin into the slot at the top of the TFU and SFU.
3. Repeat Steps 1 and 2 for the other end of the system.
4. Install the PPU to the TFU.
5. Secure the wedges at the base of the SFU.
6. Install the RTU to the TFU.
7. Check the tightness of the screws of the SFUs.

Both the installation and dismantling of the RDP Prototype I should be carried out inside the building. Also, proper personal protective equipment (safety harness, life line and anchor point etc.) against fall of person from height should be used at all times when installing, using or dismantling the RDP Prototype I. Therefore before it is dismantled the worker must first step back inside. Subsequently, the system should be dismantled as follows:

1. Remove the RTU from the TFU.
2. Remove the PPU from the TFU.
3. Remove the TFU from the SFU.
4. Dismantle the SFU from the parapet wall through the window frame.

2.3 Comments and Recommendations based on RDP Prototype I

RDP Prototype I was only an initial design of a concept which arose during conducting the previous research project. Feedback from practitioners and workers in general (as discussed in later Chapters) suggested that the following should be considered:

1. Consider other lightweight materials for the Prototype;
2. Conduct laboratory testing to ensure the safeness of the Prototype;
3. Consider how the Prototype could be packaged and transported;
4. Consider the price of sales and manufacture of the Prototype and
5. Consider the usages of the Prototype.

These considerations were incorporated in the refinement of the RDP Prototype I, and used to further develop RDP Prototype II.

2.4 Summary

The RDP Prototype I was developed in a previous project looking at fall from height accidents in repair and maintenance works. The findings from this project showed that there was a desperate need to design / provide an alternative / supplement to the current common agent for working at height, the bamboo truss-out scaffold. The development of the RDP Prototype I aimed to reduce fall from height accidents especially during repair and maintenance works. This chapter has described the development of the RDP Prototype I which has also formed the basis of the continuing research presented in this report.

Chapter 3 — Research Methodology Adopted to Develop RDP Prototype II

3.1 Introduction

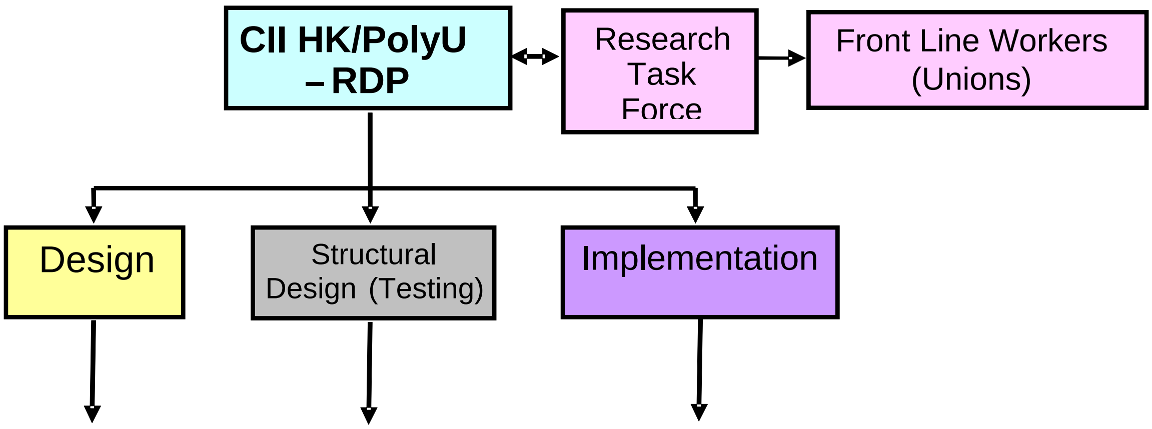
The research methodology adopted for this research project did not follow the usual procedures in conducting basic research. The reason being is this project aims at developing a product rather than researching into a topic or an issue. Hence the approach adopted was somewhat different. This section will look at the organization structure of the research team, and the approach adopted to develop RDP Prototype II.

3.2 Research Approach

Due to the skills required to develop RDP Prototype II, the research team was split into three sub-groups according to their expertise to accomplish the tasks required. These sub-groups included the Design Team which as its name implies was responsible for the design and appearance of the RDP Prototype II. In addition the Design Team, which composed mainly of design engineers, would also look at how components could be designed so that the whole system would be user-friendly to install, dismantle, use and transport. The second team was the Structural (Testing) Team and was composed mainly of structural and production engineers. They were mainly responsible for conducting a series of laboratory tests to ensure the stability of the prototype under loading, and as a result to ensure the safety of the prototype. They were also in charge of the fabrication of the prototype. The third team was the Implementation Team which was composed mainly of project engineers. The team was responsible for collecting responses from workers, practitioners, governmental departments etc. on the prototype. In order to do so the Implementation Team organized interviews, focus group meetings and demonstration sessions. The Implementation Team also produced the installation procedures instructing users to install, dismantle, maintain, use and check the prototype. The installation procedures of RDP consist of two versions; a comprehensive one targeting all parties and a simplified version for workers. The sub-teams worked closely together to support each other and the arrangement was found to be synergetic.

3.2.1 *Organizational Structure of Research Team*

Figure 3.1 shows the arrangement of the research team. The research team, which was split in to three sub-teams, was led by two project leaders. Each sub-team had its own sub-team leader which would report to the research team leaders. Each sub-team had its own team members and a research assistant/associate.



	Design	Structural Design (Testing)	Implementation
Albert Chan (BRE)	Project Leader		
Francis Wong (BRE)	Co-Project Leader		
Michael Yam (BRE)	TM	TL	
Daniel Chan (BRE)		TM	TL
C.H. Liu (BRE)	TM		
Michael Siu (SD)	TL	TM	
Albert Kwok (IC)	TM	TM	
Louis Leung (IC)	TM	TM	
W.C. Lee (IC)	TM	TM	
Edmond Lam (BRE)	TM		TM
Paul Lo (SD)	TM		
Esther Cheung (BRE)			TM*
Esther Choy (BRE)	TM*		TM
Tracy Chung (BRE)		TM*	TM

Notes : TL: Team Leader TM: Team Member *Research personnel

Figure 3.1: Organization of Research Team.

3.2.2 Project Meetings and Research Task Force Meetings

Regular meetings were one of the main techniques used to bring the research team together to share and discuss ideas, present findings, and report on the way forward. Regular Research Team meeting was held on a bi-weekly basis. Table 3.1 shows that over the nine months of the research project, nineteen Research Team meetings were held. In order to facilitate the activities of each sub-team, meetings were held for each sub-team on a need basis. The Structural Design (Testing) Team held three meetings, whilst both the Design Team and Implementation Team each held five meetings to discuss the finer activities conducted. In addition the Research Team would report to the Task Force every few months to update the progress and to discuss the activities conducted and planned.

Table 3.1: Record of Meetings.

Research Team	**Structural Design (Testing) Team**	**Design Team**	**Implementation Team**	**Task Force Meeting**
5th Jan 2007	24th Jan 2007	8th Feb 2007	23rd Jan 2007	14th Mar 2007
19th Jan 2007	4th Apr 2007	26th Feb 2007	26th Mar 2007	26th Jun 2007
2nd Feb 2007	29th May 2007	22nd Mar 2007	17th Apr 2007	
9th Feb 2007		10th Apr 2007	2nd May 2007	
2nd Mar 2007		26th Apr 2007	21st May 2007	
9th Mar 2007				
23rd Mar 2007				
13th Apr 2007				
27th Apr 2007				
11th May 2007				
25th May 2007				
8th Jun 2007				
22nd Jun 2007				
12th Jul 2007				
3rd Aug 2007				
17th Aug 2007				
31st Aug 2007				
14th Sept 2007				
28th Sept 2007				

3.3 Summary

The overall organisation of the research team is described in this chapter. Also, the responsibility of each sub-team is explained. The details of the actual research methodologies, approaches and techniques adopted for each individual sub-team will be presented in the following chapters.

Chapter 4 — Implementation Team

4.1 Introduction

Industry's recognition is crucial to the development and manufacture of the prototype. Implementation team facilitated the role of commissioning and future implementation through liaisons with the relevant industrial practitioners and related governmental departments for soliciting professional opinions on the aspects of RDP refinement and the future strategy of market launch. The consultations and discussions were mainly conducted through a series of focus group workshops and face-to-face interviews.

4.2 Activities on the Development of RDP Prototype II

Feedback opinions from industrial practitioners and end users are always essential for the refinement and further improvement of any new products. To this end, the collection of ideas in this study was carried out by means of workshops and interviews. Table 4.1 recorded the past activities associated with the development of RDP Prototype II undertaken by the research team throughout the project. Valuable opinions and suggestions from senior industrial practitioners and front-line workers were collected through the above various activities. Key findings are summarized in the following sections.

Table 4.1: List of Activities Held for the Development of RDP Prototype II.

Type	Date	Targeted group or person	Aim
Workshop	04/09/2006 (day-time)	Senior industrial practitioners responsible for working externally at height	To view and comment on Prototype I via site demonstration and feedback survey.
	29/03/2007 (night-time)	Front-line workers required for working externally at height	To view and comment on the practicability of Prototype I based on their hands-on working experience via video demonstration and focus group workshop.
Site visit	09/02/2007 (day-time)	Machinery workshop of Sun Hung Kai Properties Ltd located in Sheung Shui	To visit their in-house temporary working platform and explore their skills of aluminum welding.
Interview	06/08/2007 (day-time)	Executive Director of OSHC	To consult the feasibility on the proposed procedures for market launch of RDP Prototype II via face-to-face interview.
	13/08/2007 (day-time)	Senior Structural Engineer of BD	

4.3 Workshops

Industrial practitioners with relevant extensive experience in the construction industry were invited to attend a site demonstration of the RDP Prototype I held at the Industrial Centre of PolyU. Their opinions and suggestions were collected through a feedback survey. The Prototype I was also introduced to the front-line workers with working externally at height experience. Practical suggestions had been given through focus group discussions.

4.3.1 Demonstration Workshop with Senior Industrial Practitioners

The feedback survey after the demonstration workshop aimed to collect the first impression on RDP from senior industrial practitioners. The inclusion of nine sets of multiples choice questions and one open-ended question has invited the respondents to comment on the RDP Prototype I in the aspects of practicability and acceptability, as well as to identify rooms for improvement. A sample of survey questionnaire is included in Appendix 1 for reference. Replies from nine respondents were received and their background was tabulated in Table 4.2. All of them were holding managerial position in either construction safety or building repair and maintenance.

Table 4.2: Profiles of Survey Respondents.

Respondent's job nature		Respondent's working experience	
		in construction safety	in building repair and maintenance
1	Technical service manager	10 yrs	10 yrs
2	Assistant technical service manager	3 yrs	3 yrs
3	Safety manager	15 yrs	Few
4	Associate professor	10 yrs industrial experience, 0 yrs in safety	4 yrs in public building maintenance sector
5	Safety manager	> 10 yrs	Little
6	Chief officer	34	10
7	Executive	> 30 yrs	> 30 yrs
8	Promoting & monitoring site safety	12 yrs	6 yrs
9	Anonymous	-	-

Preliminary key findings indicated that their attitude towards the RDP was affirmative. Comments towards each question were analyzed as follows.

Q1: The RDP is safe to use for external repair and maintenance works.

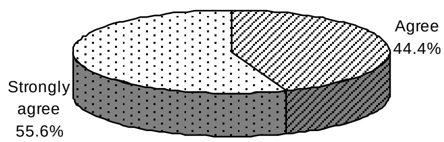


Figure 4.1: Safeness of RDP.

In Figure 4.1, all respondents showed their confidence over the safeness of RDP. More than half of them strongly agreed the RDP is secured for undertaking external repair and maintenance works.

Q2: The speed of installation/dismantling is appropriate in a real life situation.

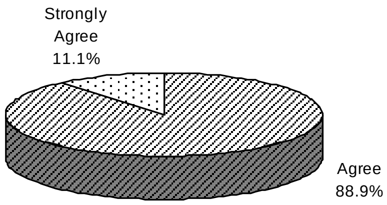


Figure 4.2: Speed of Installation/Dismantling.

Regarding the speed of installation and dismantling, the findings as shown in Figure 4.2 has indicated that all of them agreed the RDP to be a time-saving device. It was demonstrated that each of the installation and dismantling procedures could be completed within 10 minutes. This has benefited greatly to the users who could minimize their preparatory time and enhance their working efficiency.

Q3: The RDP is simple to use for workers.

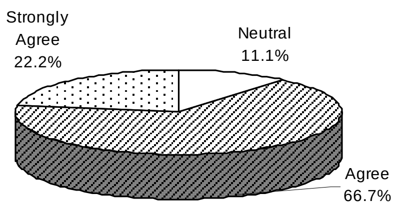


Figure 4.3: Suitability for Workforce Level.

Front-line workers are expected to be the end-user of RDP. It is important that the design of RDP should be user-friendly which could be handled easily by workers. About 89% of the respondents indicated in Figure 4.3 perceived that the RDP is not a complex device for practical use.

Q4: The RDP could replace the bamboo truss-out scaffold.

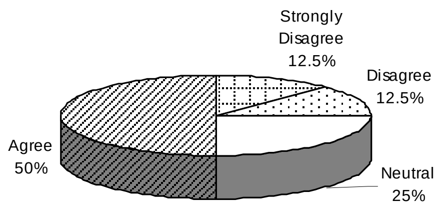


Figure 4.4: Comparison to Existing Scaffold System.

Only half of the respondents believed that the RDP could replace the bamboo truss-out scaffold while a quarter of them reserved on this issue.

Q5: The design of the RDP does not need improvement.

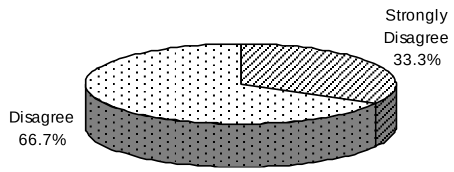


Figure 4.5: The Essential of Improvement.

Although practitioners exhibited supportive viewpoints to the RDP, Figure 4.5 has revealed the necessity of improvement to accommodate in the real applications. All of them expected that the RDP should undergo fine tuning before launching.

Q.6: The RDP is too heavy.

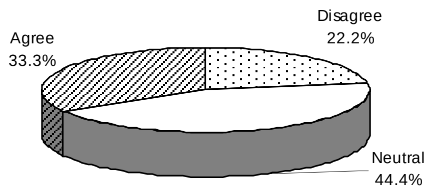


Figure 4.6: The Concern of RDP's Weight.

The weight of RDP is one of the concerns. One-third of respondents in Figure 4.6 believed the RDP to be too heavy owing to the fabrication solely by steel. Problems associated with transportation and installation at height would arise.

Q7: I would encourage my staff/colleagues to use the RDP.

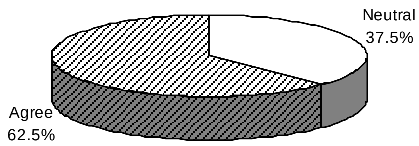


Figure 4.7: The Recognition of RDP.

On the whole, about two-third of the respondents expressed their willingness to recommend the use of RDP to their staff as in Figure 4.7.

Q.8: The RDP should have fewer components.

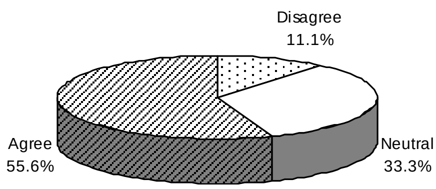


Figure 4.8: The Quantity of RDP Components.

Regarding the quantity of components, Figure 4.8 recorded that more than half of the respondents concurred the number of RDP components to be reduced so as to ease the process of transportation and installation.

Q.9: The RDP appears to be durable.

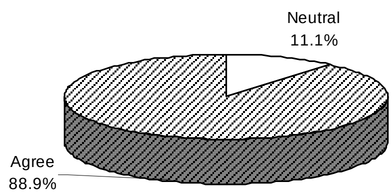


Figure 4.9: The Durability of RDP.

Steel and wood were the major fabrication materials on RDP Prototype I. About 89% of the respondents showed their supportiveness on its durability as in Figure 4.9.

Q.10: The RDP is useful for the majority of old residential buildings in HK.

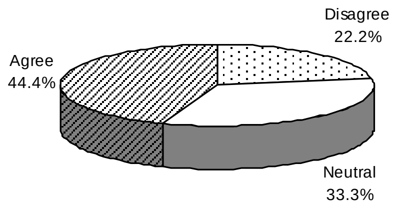


Figure 4.10: The Applicability of RDP in HK Old Residential Buildings.

The viewpoint of respondents dispersed on the application of RDP at old residential buildings in Hong Kong. As in Figure 4.10, about 44% of them thought the RDP to be useful to working at height for old residential buildings while a 22% of opposition was observed on this issue.

Q.11: The RDP should be designed using other materials such as aluminum.

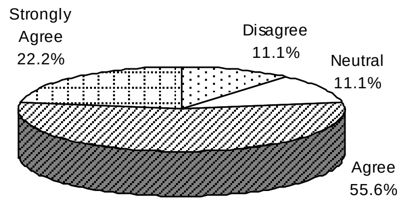


Figure 4.11: Alternative Fabrication Materials.

Respondents' attitude towards alternative fabrication materials was mostly supportive. Findings from Figure 4.11 indicated about 78% of them agreed that the RDP should be designed using other materials such as aluminum.

4.3.2 Focus Group Workshop with Front-line Workers

A focus group workshop on the RDP Prototype I was held on the night of 29th March 2007. Being the hosts of the RDP project, PolyU and CII-HK had invited the Hong Kong General Building Contractors Association and the Hong Kong Construction Industry Employees General Union to take part in the workshop. The 1.5 hr workshop meeting had comprehensively introduced the concept of RDP and valuable suggestions were gathered.

Targeting the front-line workers in particular with external height working experience, a number of 21 people have participated (Figure 4.12). The demonstration of RDP installation and dismantling was delivered through the video recording.

Figure 4.12: The Focus Group Workshop on 29th March 2007.

Afterwards, the participants were divided into four groups. Based on the pre-assigned questions on the aspects of safeness, adoptability and fabrication materials, different comments were made. Generally, their attitude to the RDP was supportive. They also expressed their concerns over the practical application and the needs in the real market. Finally, a proxy from each group had been nominated to summarize the key viewpoints. The minutes of the workshop was recorded in Appendix 2 (Chinese version only) while the key points of the discussion were outlined as below.

Q1: Do you think that the RDP could be applied to repair and maintenance works at external height? Any possible risks induced?

They pointed out the possible risk might arise from the uncertainty on the strength of external parapet wall. There is no proof on the hardness of wall in old residential buildings. The RDP might not be able to sustain on weaker walls. The worry may be eliminated if the RDP is applied to modern buildings.

Q2: How is the speed of RDP installation or dismantling compared with that of bamboo truss-out scaffold?

The installation or dismantling of RDP is efficient. Participants agreed that such platform should be convenient for small-scale maintenance works.

Q3: Could the front-line workers install and use the RDP without difficulties?

The installation is easy to handle. It was suggested to arrange half-day safety training on the proper use.

Q4: Could the existing bamboo truss-out scaffold be replaced by the RDP? Please explain.

Participants did not think that the RDP could replace the bamboo truss-out scaffold at all owing to its limitation by the environments, the usages and locations. In addition, they pointed out that the RDP could not be applied to works relating to window frame replacement which has been believed to be one of the most common minor repair works in the industry recently. The RDP is however feasible for repairing air-conditioners and glass replacement works. The budget for such repair works could be minimized from the cost spending on the erection of bamboo scaffold.

Q5: Does the RDP require further improvement?

<u>From the design point of view</u>

The access area is limited due to a lack of feasibility on the level adjustment of RDP. Besides, the designated dimensions of RDP might restrain from different sizes of windows. The flexibility of dimensions was suggested to cope with different working conditions. In addition, wooden planks should not be used for standing toe-board due to its easy wear and tear problem.

From the material point of view

It was suggested that alternative materials such as zinc and aluminum alloy should be used for the standing toe-board. Also, the use of sinkholes could prevent water seepage.

From the installation point of view

Plastic pads should be inserted between the screws and inner wall to protect from any scratches while fixing. The railing should be securely fastened and should not allow for any movement from leaning. The locking device should be replaced by interlocking system.

Q.6 Does the RDP contain too many components?

It was suggested the number of components to be reduced. Besides, the transportation of RDP to work location should be considered. The self-weight of platform is too heavy (95 kg) for two workers.

Q.7 Is the RDP durable?

Long exposure under the sun might cause fragile on the wooden plank.

Q.8 Could the RDP be applied to repair and maintenance works in old residential buildings?

The usage of RDP is limited to the window size and the access level. They were concerned about the practical application and the needs in the real market.

Q.9 If the RDP launch to the market in the near future, will you consider to own one?

They were willing to adopt the RDP as a temporary working platform for maintenance work at external height if its safeness could be certified by the Labour Department (LD) or other recognized certification bodies. The provision of rental scheme rather than own purchase could attract greater interest to end-users as the space for storage could be saved.

4.4 Site visit to the Machinery Workshop in Sheung Shui

With the generous offer from Sun Hung Kai Properties Ltd (SHKP), a site visit to their self-developed temporary working platform was held on 9th February 2007 in their machinery workshop located nearby the Golf Club in Sheung Shui. Guided by the Construction Plant Manager, our team members in a group of 10 spent a valuable afternoon for discussion there.

A similar temporary working platform supported by a vertical prop has been investigated by the SHKP group. The demonstration on the installation and dismantling procedures has given us an insight into the materials and techniques involved. Besides, we visited their aluminum welding workshop. With their skillful welding technique, the strain test has indicated the bearing capacity of aluminum frame was comparable to that of steel frame. This result was encouraging in the consideration of steel replacement by alternative lighter materials for the RDP. The consultative discussion with their staff has provided us with useful information on the practicability of RDP.

4.5 Proposed Market Launch of RDP

The flowchart indicated in Figure 4.13 explicitly outlines the proposed steps of RDP market launch. Being the RDP designer, the research team is responsible for managing the supporting documents which include testing certification from accredited laboratory and the application of patent. Once the license is secured, the production of RDP will be outsourced to licensed manufacturer based on the finally approved design. Maintenance contractors or property management companies could purchase the RDP system from the appointed distributors or suppliers. To fit for specific conditions of application, both purchase and rental schemes are proposed. The responsibility of insurance shall fall onto the RDP owners. For the case of renting, users are supposed to bear the insurance fee which is supposed to be included in the rent fee. Proper use of RDP shall be ensured through recognized training courses. Certification issued from authorized party should be acquired prior to the use while inspection and maintenance works shall be responsible by competent persons who are qualified from relevant recognized training.

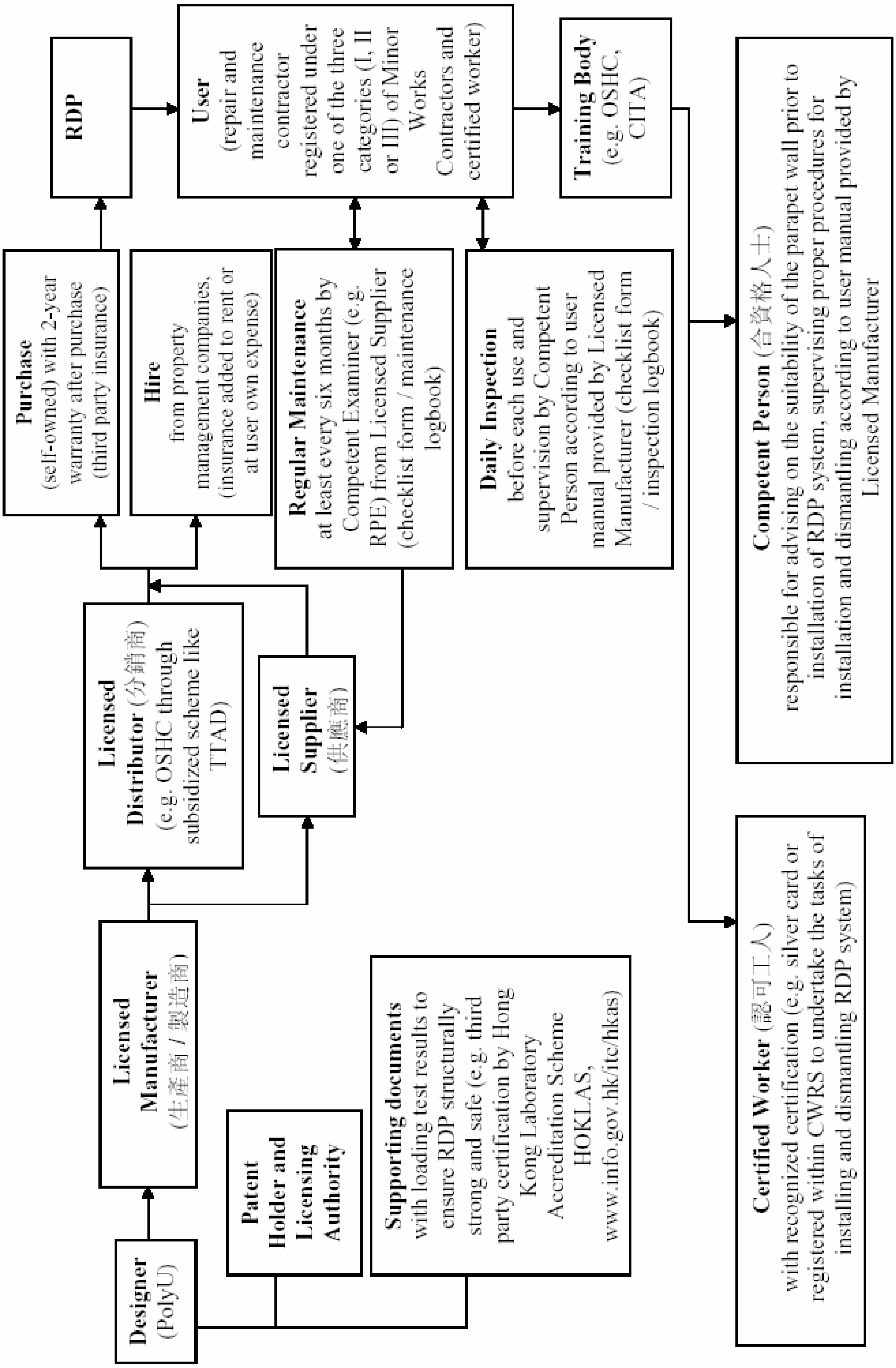


Figure 4.13: Flowchart showing the Market Launch of the RDP in Building, Construction, Repair and Maintenance Sectors.

4.6 Interviews

Based on the proposed market launch as depicted in Figure 4.13, two interviews with related government departments were conducted. The conversation has given valuable enlightenment on the preparation of materials for launching the RDP.

4.6.1 Interview with Occupational Safety and Heath Council (OSHC)

The flowchart for the proposed market launch of RDP as in Figure 4.13 was sent to the Executive Director of OSHC prior to the meeting on 6th August 2007 for comments. Full meeting notes may be found in Appendix 3 while the major comments were summarized in the next paragraph.

The visit to OSHC was intended to glean feedback on the proposed approach for market launch and gather information about the matter of possible subsidization of RDP from government. The interviewee and his teammate expressed that any products intended to be subsidized by OSHC would only be considered subsequent to the approval of LD. They raised their concern over LD's approval as there is no unique international standard or specification on the proposed RDP. Moreover, they further commented on the sole distributor arrangement might cause a lack of competition in the market. According to their experience, the subsidization approval should be made more difficult owing to the sole distributor. Also, they doubted about who should take up the responsibility of insurance. In case of purchase, owners should be fully responsible for the insurance. If the RDP is rented, the contractor or workers should purchase the third party insurance similar to the usual practice as in car rental.

4.6.2 Interview with Buildings Department (BD)

Further to the interview with OSHC, another interview with a Senior Structural Engineer of BD was carried out on 13th August 2007. With respect to the flowchart of the proposed market launch and the comments from OSHC, this visit aimed to consult the position of RDP upon the enforcement of minor works. Detailed meeting notes may be found in Appendix 4 while major contents of the meeting were summarized as below.

The interviewee made several comments on the logistic arrangement from the flowchart. The research team should have thorough understanding of the market on the demand of RDP before the manufacturing stage. Preparation works such as patent application and certification of laboratory testing should be ready as the first step. He also expressed that approval from LD should be sought. Further, the concept of “agent” could be fused into the flowchart. The employment of agent could assist in the marketing and liaison duties with external contractors or relevant government departments. Besides, he supported that the RDP should fall into the category of “minor works”. Such kind of information has not yet available as its by-law is pending to enact.

The comments from the interviewees of OSHC and BD have been addressed and incorporated into the revised flowchart found in Appendix 5.

4.7 Other RDP Reference Materials

To address comments gathered from some external parties, the installation procedures and videotaping of installation/dismantling procedures form a complete set of reference materials supplementary to this study.

4.7.1 RDP Installation Procedures

Safety is the foremost consideration in the development of RDP. Although users are expected to undergo sufficient training prior to the first use, the provision of installation procedures could further insure them from any misuse and serve as a quick reference in case of contingent conditions. The draft RDP installation procedures are aimed at setting out guidelines and steps to both supervisory and workforce levels for perusal.

1. Supervisor's Version

The supervisor's version covers comprehensive information associated with the application of RDP. The installation procedures mainly include the following sections while the table of content can be found in Appendix 6.

- Introduction – where the applications, conditions for use, responsibilities of related parties and limitations of RDP were outlined;
- Definitions – where various roles of related personnel involved and the key technical terms were clearly defined;
- Management of Safe Operation – where the safe system of work was stated;
- Safe and Proper Use – where the procedures for installation and dismantling, details of daily inspection, the responsibility of each parties, the safety precautions and the emergency plans were included;
- Regular Maintenance – where the frequency and record of maintenance were described; and
- Specifications – where the references on standards, materials, dimensions, weight and strength were indicated.

2. Worker's Version

The RDP installation procedures in worker's version provide a quick reference for on-site workers. Being extracted from the supervisor's version, it provides the proper installation/dismantling procedures of RDP system with appropriate illustrative diagrams/photos and emphasizes on the troubleshooting solutions in case of any emergency.

4.7.2 Videotaping on the installation of RDP Prototype II

The installation process of RDP Prototype II has been videotaped by the research team on 18th September 2007 at Industrial Centre of PolyU for demonstration or referencing purpose. The installation time was kept within 10 mins and steps of installation can be viewed from the video as attached in Appendix 7.

4.8 Summary

Industrial practitioners and government departments contributed fruitful ideas on the development of RDP Prototype II. Key results and findings from the demonstration workshops with practitioners and workers, site visit and face-to-face interviews with related government agencies have been reported in this chapter. The two-way communication did not only benefit the project itself, the industry participation could arouse their interest and necessity on the solutions of fall from height accidents in the construction industry. Though the proposed market launching plan of RDP is preliminary and too green to carry out for the time being, the research team does believe that keeping on this direction could generate a more mature plan later after soliciting more opinions and suggestions from both the industry and government.

Chapter 5 — Design Team

5.1 Introduction

The RDP is believed to be a breakthrough for the industry. Not only it can raise the efficiency of construction work at height, it can also be applied into various circumstances such as, inspection of external walls, fixing water seepage problems, repairing windows, etc., at an economical cost. To enhance the applicability of RDP, several product design concepts have been input in the design of RDP Prototype II.

5.2 Design Considerations

From the point of view of "design", we need to consider thoroughly and strike a balance between its practical application as well as marketability. The RDP Prototype II was developed (as in Figure 5.1) based on the key concerns as follows:

- User friendliness,
- Modular design, and
- Safeness.

Figure 5.1: The Outlook of RDP Prototype II.

5.2.1 User Friendliness

As the name of RDP, *rapid* and *demountable* were two key design requirements of the platform. Although different individual needs and preferences of workers — users — may be varied, user-friendly for most of the workers in rapid installation and demounting was an essential consideration in the design of the RDP. For example, equipment for working at height should be simple in nature because complicated process affects the effectiveness and efficiency of the RDP installation process. Therefore, we applied safe and fast locking systems into the RDP. One of the features was the simple locking devices which could ensure all parts were well locked systematically. Its quick release (and unlocking) system was essential too. In particular, there was no loosing part (such as pins) that all of the moveable and detachable small parts were all well-fixed to the main body or parts of the RDP. This design feature could prevent the fall accidents from the RDP setup and demounting process. As a whole, it was expected a high recognition from workers towards the RDP could be gained.

5.2.2 Modular Design

Based on the research analysis through survey, meetings, case studies, and testing; we generated the data to work out the most feasible modular design. The RPD was specially designed because each part was in standard style as in Figure 5.2.

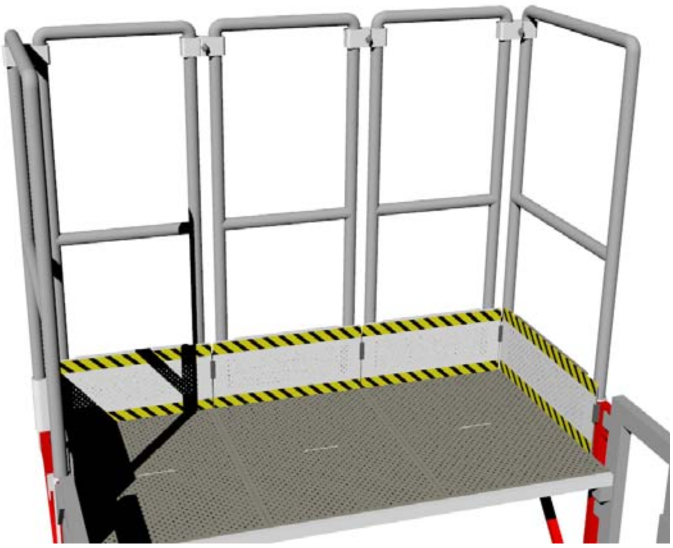


Figure 5.2: The Application of Modular Concept.

Workers could set up the RDP easily without any obstacles because of the simplicity and uniqueness of the parts from the appearance, length, size, material, etc. Through simple trainings and assistance of the installation procedures, the workers could acquire the installation skills easily.

There were two major directions — design philosophy — for the modular design of the RDP. The first direction was that most of the parts with the same function were standard in color, form and dimension. They were exchangeable and also replaceable. In other words, the degree of misplacing the parts with same function was minimized. For example, the platform panels of the RDP were the same. There was no need to have a particular sequence or position of individual panels attached to the RDP.

The second direction was the information — indication — on particular part(s) and module(s) serving particular purpose and drawing attention on specific location. In other words, workers could recognize and distinguish the function and position of individual parts easily. This direction related to the "product semantics" of the design. For examples, the tenons of the railing panels (i.e., the tubes with open-ends of the railing panels) and the sockets for the tenons provided on the base-framework of the RDP were easily be recognized and distinguished by workers during installation. The upper and lower positions and the out-faced and in-faced surfaces of the toe-boards were also easily recognized and distinguished by workers. Although the widths of front-railing panels and side-railing panels were different due to the particular requirement of the available working area, the dimensions of the base-framework gave clear product-semantic information to workers to distinguish and locate the panels in different positions easily.

5.2.3 Safeness

Safety is the main concern in the design of the RDP. Among all, the simple but critical consideration of the design of the RDP was that it had to be mounted firmly onto the walls.

Moreover, the risk of falling objects was another important consideration in the RDP installation process. Therefore, safety hooks could be found in each part of the RDP. Workers were required to hook each part when they were doing the installation process, hence ensuring safety in this aspect. Also, toe-boards were inserted on outer boundary of the platform. It was linked with the base of the railing panels. This design feature prevented the parts throwing out from the working platform.

In addition, the toe-boards also served as a kind of safety-precaution device in another way by securing other parts of the RDP. For example, the toe-boards could strengthen the framework of the overall railing panels and also secured the platform panels in position.

Bright and florescent color or zebra hatching stripes/patterns were added on some critical parts of the RDP such as the edges of the toe-boards to provide more information — warning — to workers.

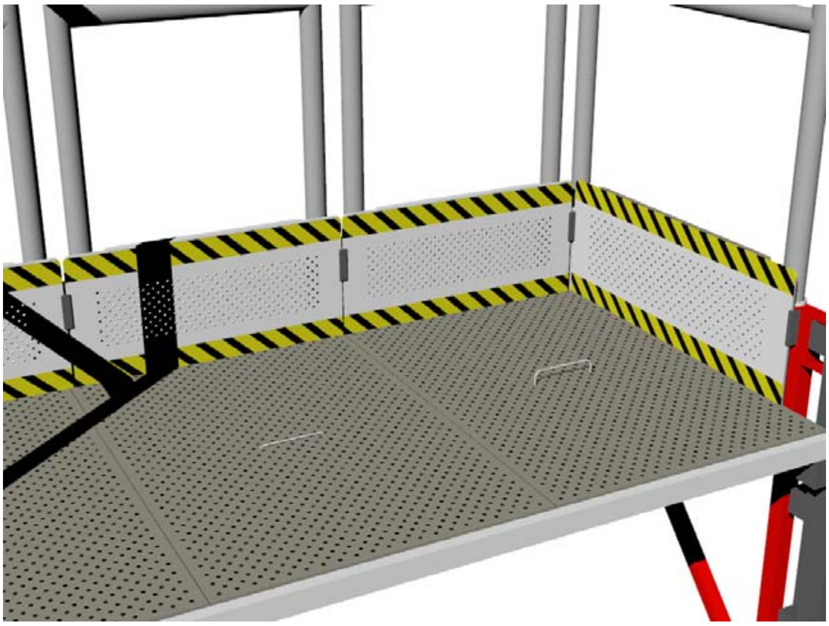


Figure 5.3: The Platform by Aluminum.

For prototype II, the platform panels were made of aluminum (Figure 5.3). Thus, the panels provided a strong support for the working environment. It was more durable and suitable for outdoor working environment because the usability of the platform was greatly improved. Correspondingly, the total cost could be lowered because of it was more durable and more bearable to normal wear and tear. As indicated in Figure 5.4., sinkholes of the panels were provided to stop water from cumulating on the platform. The sinkholes also formed a non-slippery surface to avoid workers from slipping in a soggy environment. Attached handles were provided to allow easy placing and removing of the platform panels.

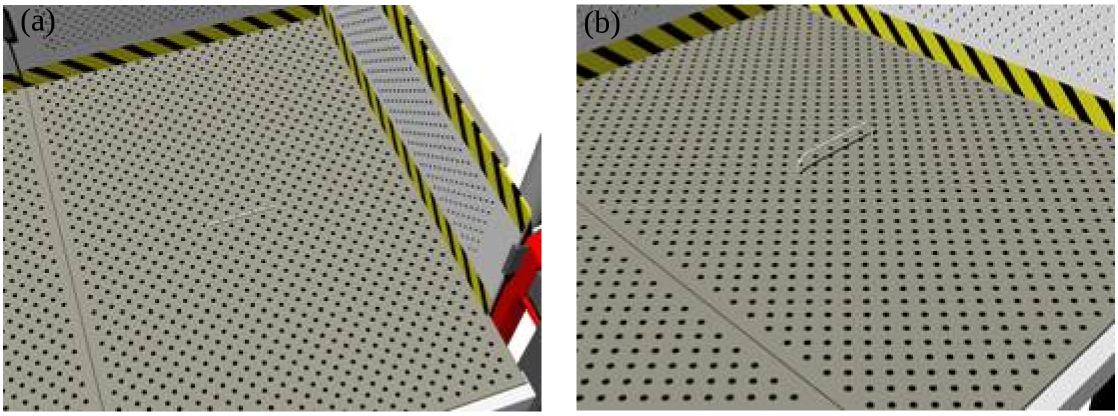


Figure 5.4: (a) Sinkholes of the Panels and (b) Attached Handle in the Platform.

5.2.4 Product Semantic

As indicated above, product semantic was one of the emphases in the RDP (Figure 5.5).

Figure 5.5: The Concept of Product Semantic is Reflected by the Reflective Label Toe-boards.

Symbolic meanings of the products were important to workers. The interpretation (i.e., feeling, perception) feeling of a product affected the confidence of the workers towards it and even its application among the public. In the RDP, the dimensions of the railing panels and platform panels (e.g., thickness) were carefully designed for the loading needs.

Moreover, the design of each part of the RDP was specially considered to give clear messages to workers on how to use it. For example, looking at the interlocking system of the railing panels, workers could easily understand and recognize how the system should be operated. The bright and florescent color of the toe-boards caught the attention of workers to prevent accidents.

The installation of the overall structure of the RDP was in a logical sequence. Starting from the overall framework to small particular parts; and from the bottom to the upper parts were good illustration of the logical sequence of the installation of the RDP. In sum, quantity and quality were two pivotal elements in our design which enabled workers to use it with confidence.

5.2.5 Innovation

There were several breakthroughs in the design of the RDP. For example, Figure 5.6 showed that a new interlocking system was applied for securing two railing panels together in a safe and also convenient way.

Figure 5.6: The Interlocking System on the Railing of RDP.

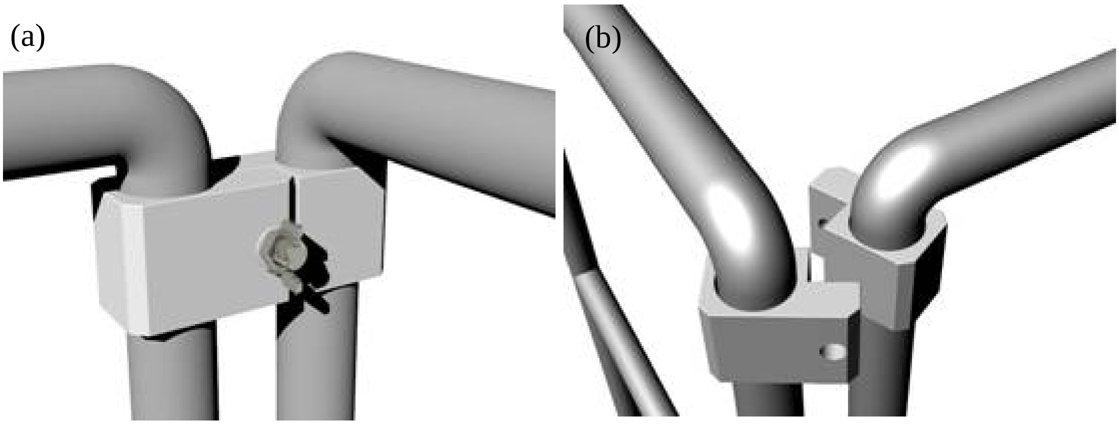


Figure 5.7: The Interlocking System in (a) Locking Format and (b) Opening Format.

The interlocking system was magnified in Figure 5.7. The system was attached at the top of each railing panel. It could provide flexible lock with horizontal rotations (Figure 5.8). Workers could fix all railing panels together through the interlocking system.

Moreover, the toe-board was designed not only to serve as a guard to prevent falling of objects and accidents, it was also used to secure the platform panels in position; and no additional device was required to satisfy the latter function.

Figure 5.8: The Interlocking System in Two Directions.

5.3 Description of RDP Prototype II

With the incorporation of the design considerations, the RDP Prototype II was greatly modified and the installing / dismantling procedures have been updated accordingly. The description of RDP Prototype II has been included in the next paragraph and the major differences in Prototypes I and II were compared in Chapter 7.

In the fabrication of RDP Prototype II, steel and aluminum were adopted as the major materials. Except the change in materials in items 3 & 4, the four major units remain the same as in Prototype I. They are:

1. Supporting Frame Unit (SFU);
2. Triangular Frame Unit (TFU);
3. Platform Panels Unit (PPU) and,
4. Railing Panels and Toe-boards Unit (RTU).

The SFU and TFU were manufactured using Steel SHS of 50×30×3mm and 25×25×2.5mm respectively. Three square PPUs made by aluminum rest on the TFUs. Four sets of railing panels in aluminum were slotted into the sockets and were securely fastened by pins. The five toe-boards were made of aluminum. The total weight of the RDP Prototype II is 81 kg. The SFUs is the heaviest unit among the four.

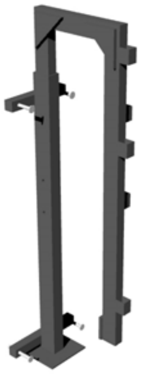


Figure 5.9: Supporting Frame Unit (SFU)

Figure 5.10: Triangular Frame Unit (TFU)

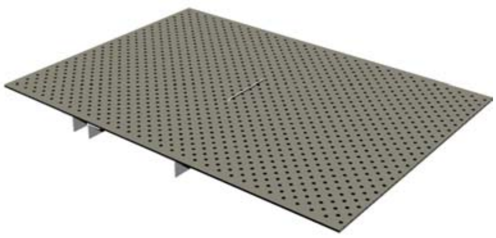


Figure 5.11: Platform Panels Unit (PPU)

Figure 5.12: Platform Panels Unit (PPU)

Figure 5.13: Railing Panels and Toe-boards Unit (RTU)

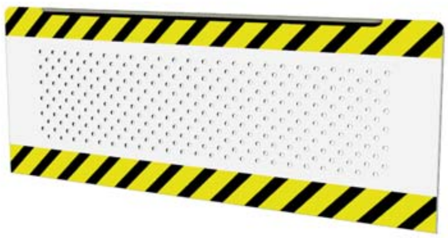


Figure 5.14: Railing Panels and Toe-boards Unit (RTU)

5.3.1 Installing / Dismantling Procedures

The installing / dismantling procedures are generally similar to those in Prototype I. Revised procedures of the RDP Prototype II were described as follows:

1. Set up the SFU to the parapet wall through the window frame. The SFU can be adjusted to appropriate height. Gently tighten the screws on the SFU to bear against the wall.

Figure 5.15: Exterior SFU Setting.

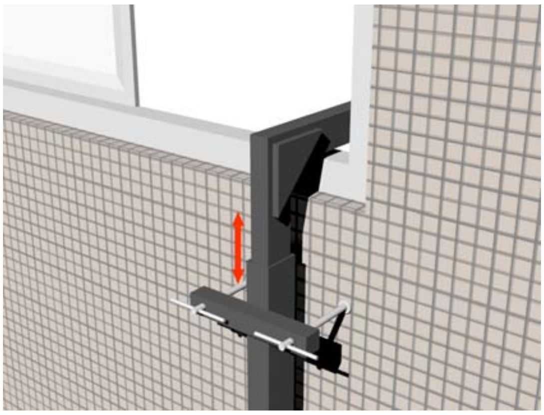


Figure 5.16: Adjust to Appropriate Height.

2. Install the TFU to the SFU at the desired level. Insert the anchor pin into the slot at the top of the TFU and SFU.
3. Repeat Steps 1 and 2 for the other end of the system.

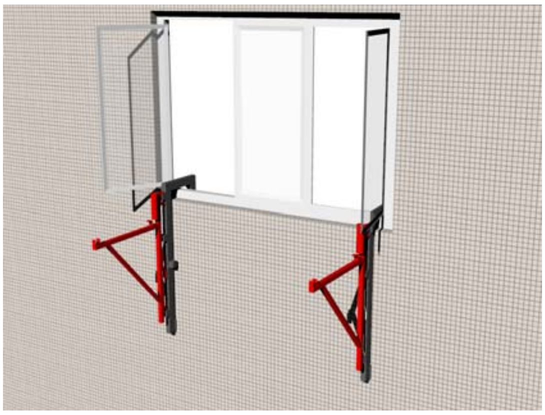


Figure 5.17: Install the TFU to the SFU.

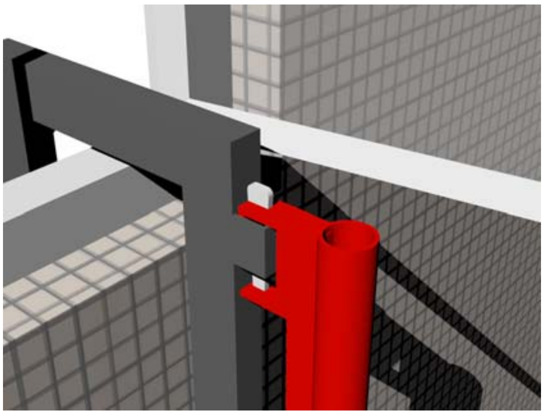


Figure 5.18: Anchor Pin into the Slot.

4. Install the PPU to the TFU.
5. Slot each set of RTU to the SFU and secure by the pin on the socket.

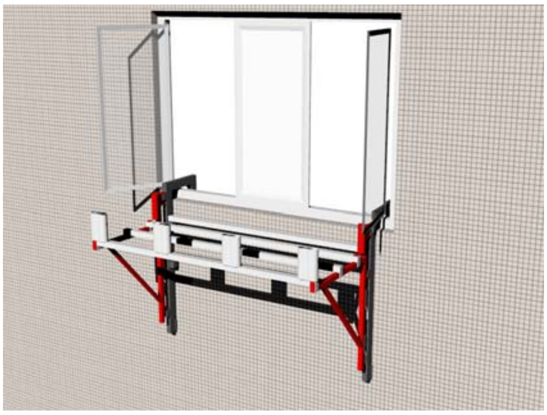


Figure 5.19: Install the PPU to the TFU.

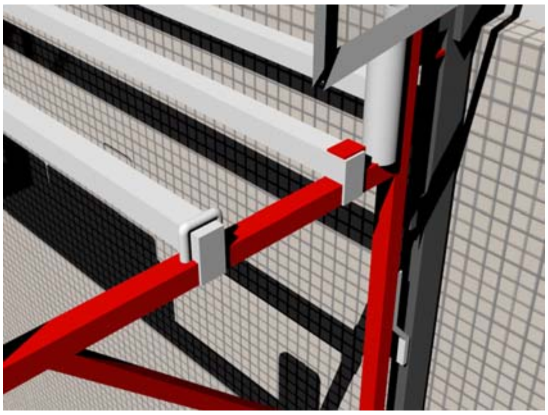


Figure 5.20: Secure the TRU and SFU by Pin.

6. Interlock the RTU by the pre-install locking system on the railing panels.
7. Check the tightness of the screws of the SFUs.

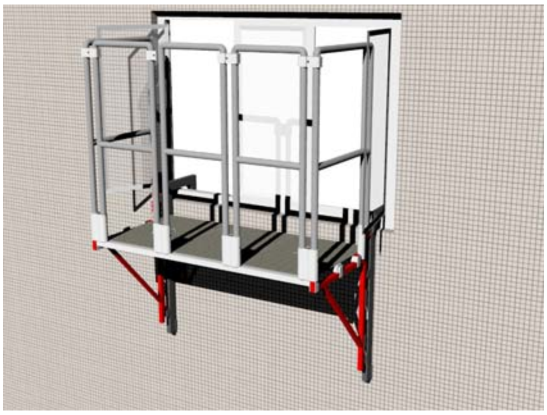


Figure 5.21: Install Railing Panels to the PPU.

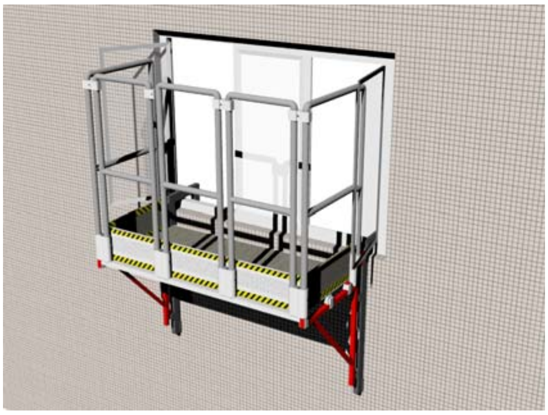


Figure 5.22: Install Toe-board to the PPU.

Similar to RDP Prototype I, the installing and dismantling could be carried out inside the building. It has been demonstrated that the installation of RDP Prototype II could be completed within 10 min which is about 5 min faster than the previous model. Also, the dismantling is only the reverse of the above process. Such design is handy and could be easily erected by one worker.

5.4 Summary

The input of engineering design is one of the major advancements in the development of RDP Prototype II. The design was based on the workers' need and focally sought solutions to the limitations in Prototype I. Feedback from various stakeholders has greatly contributed to the improvement. Several re-designs were executed upon receiving negative comments from the stakeholders. The process may keep on cycle until an optimum solution is obtained. The RDP Prototype II is yet to be perfect; the gather of comments could further boost the practicability and applicability on the RDP.

Chapter 6 — Structural Design (Testing) Team

6.1 Introduction

Based on the Stage I study, project a RDP prototype I was developed. The RDP Prototype I was constructed using available materials at that time combined with sound engineering judgement. For this Stage II study, a new prototype (RDP Prototype II) will be re-designed based on engineering principles and current design practice in order to ensure a sound and safe design.

6.2 Structural Design Criteria

In the structural design of the RDP Prototype II, the following points were considered.

1. The reduction of weight is a primary concern for front-line workers using the RDP since the triangular frames have to be installed outside the building. The weight of RDP Prototype II should be minimized.
2. RDP Prototype II should be structurally sound and adequate according to the requirements of the local codes and standards.

6.2.1 Load Path

Drawings of the RDP Prototype I are shown in Figure 6.1. Basically, the structural form of RDP Prototype I and II are similar, especially for the U-frames and the triangular frames. Load path for the RDP Prototypes is shown in Figure 6.2. Loadings from the platforms are transmitted to the triangular frame through the secondary beams. The loads from the triangular frame were then transferred to the U-frame through the connections. Loads from the platform induced a moment to the system which was resisted by the couple generated by the horizontal reactions provided to the U-frames as shown in Figure 6.3. The figure also shows the vertical reaction provided by the slab to the Base-Support.

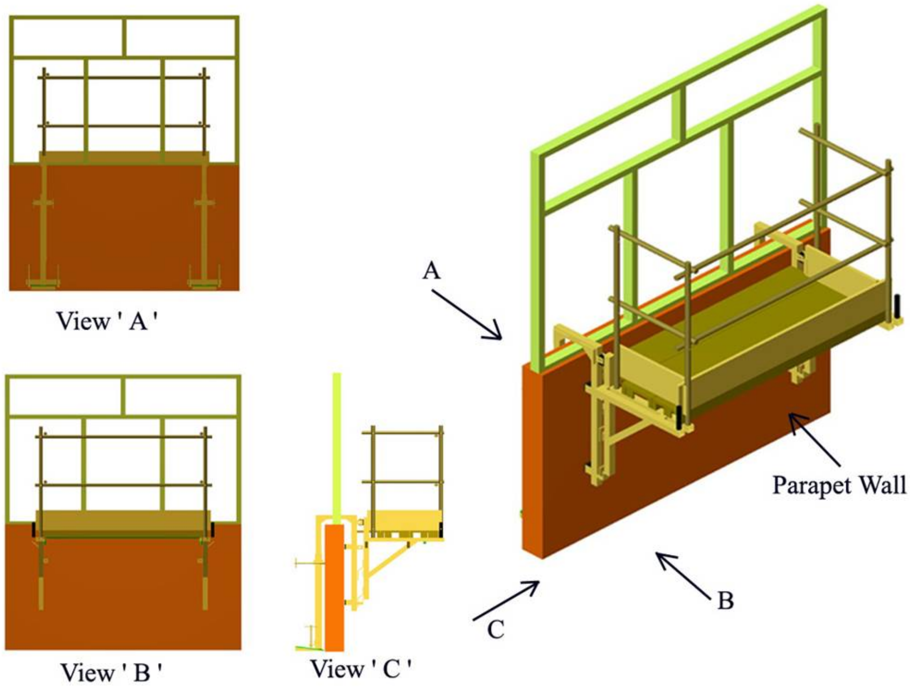


Figure 6.1: RDP Prototype I.

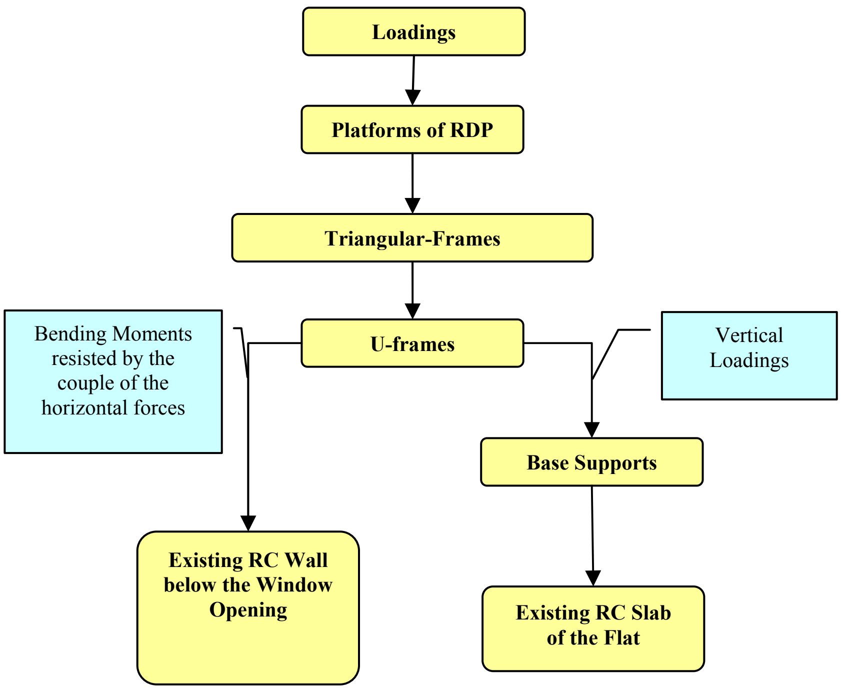


Figure 6.2: Load Path of RDP Prototypes.

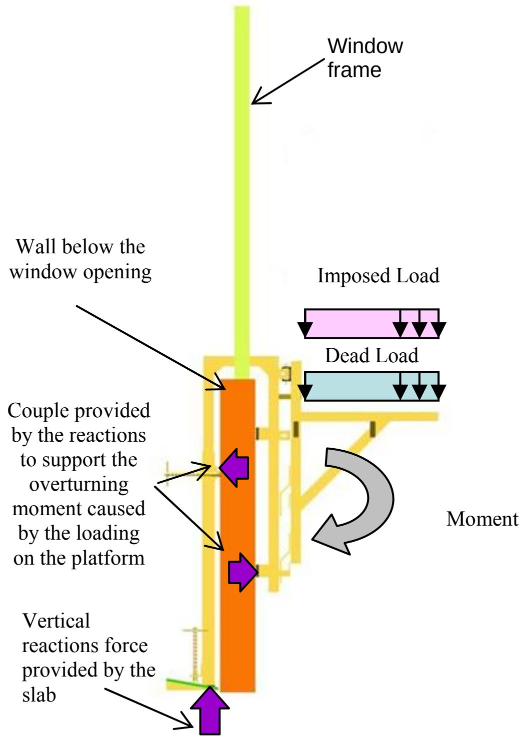


Figure 6.3: Locations of Loads and Reaction of RDP Prototypes.

6.3 Structural Design Procedures

To produce a structurally sound and safe RDP Prototype II, structural analysis and design of the prototype have been carried out. The procedures of the structural analysis and design are summarized in Figure 6.4. RDP Prototype I was tested in the first stage of this project. The experimental report of RDP Prototype I was included in section 6.4 of this report. A numerical model of RDP Prototype I was developed by using a commercial analysis package, SAP2000. SAP2000 is a commonly used structural analysis computer program. A series of SAP2000 structural programs has been pre-accepted by the Buildings Department of the HKSAR government.

In order to validate the numerical model, the numerical analysis results were compared with that of the experimental results and a good comparison of the results were obtained (this will be discussed in the later sections). Based on the validated numerical model, two new numerical models of RDP Prototype II were generated. One of the numerical models was generated using SAP2000. Member forces such as moment, shear force and axial force were obtained from this model. These forces were used in the structural members design. Another numerical model of RDP Prototype II was generated using a commercial finite element analysis package, ABAQUS. ABAQUS is a commonly used finite element program. A more refined numerical model can be built by this program. Stresses at the connections of the RDP can be obtained and used in the structural design of the connections.

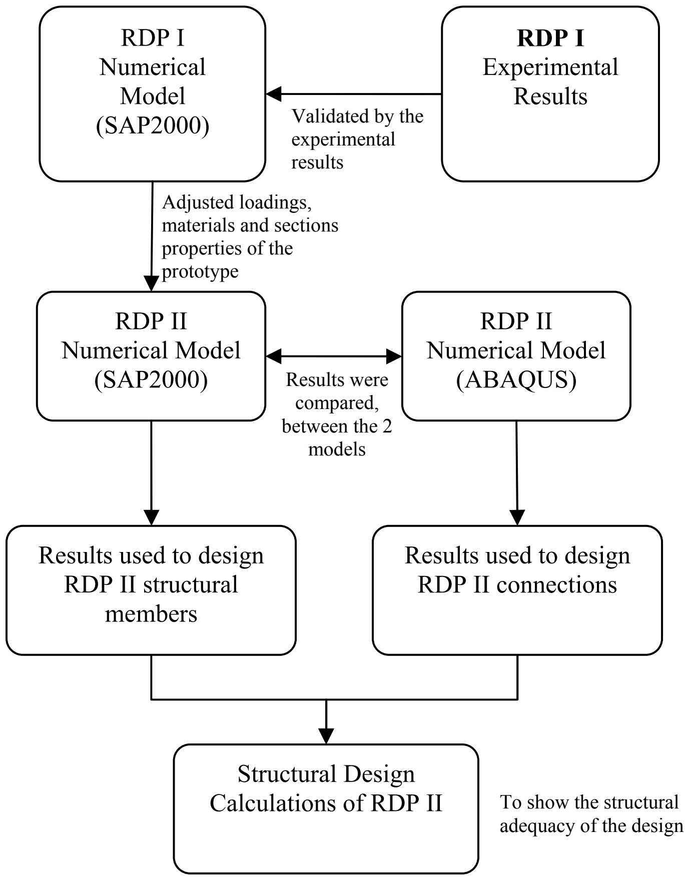


Figure 6.4: Structural Analysis and Design Procedures for RDP Prototype II.

6.3.1 Design Requirements and Loadings

To ensure that the RDP Prototype II is structurally safe, appropriate design load factors, design loadings (dead, imposed and horizontal) and allowable deflections should be used. In order to determine the practical loadings and the performance requirements for the RDP, both local and international standards and codes of practice were studied extensively. A summary of these documents is listed in Table 6.1. The standards and codes of practice are:

1. Guidelines on the Design and Construction of Bamboo Scaffolds, Building Department;
2. BS EN 12811-1:2003 Temporary works equipment - Part 1: Scaffolds - Performance requirements and general design;
3. BS EN 1004:2004 Mobile access and working towers made of prefabricated elements - Materials, dimensions, design loads, safety and performance requirements;
4. BS1139-5:1990 HD 1000:1988 Metal scaffolding - Part 5: Specification for materials, dimensions, design loads and safety requirements for service and working scaffolds made of prefabricated elements;
5. Guidelines on the Design and Construction of Bamboo Scaffolds, Building Department;
6. Code of Practice for Bamboo Scaffolding Safety, Labour Department;
7. Code of Practice for Metal Scaffolding Safety, Labour Department;

The structural design was conducted according to the following two specifications.
1. Code of Practice for the Structural Use of Steel 2005, Buildings Department.
2. BS 8118: Part 1: 1991 – Structural use of Aluminium.

The Code of Practice (CoP) for Bamboo Scaffolding Safety (Labour Department, 2001) was analyzed to be the most relevant in this study and hence was used as the main source of referencing for these tests. Based on this CoP the **imposed loading with 2 kPa or 2 kN over any square with a 300mm side and at the end portion of a cantilever** (For General building work, purpose including brickwork, window and mullion fixing, rendering, plastering) were used as the characteristic load for the testing program. Although the RDP is a temporary structure, load factors were used in the design process to ensure that adequate safety margin is allowed in the final design. Therefore, load factors of **1.4 and 1.6** were adopted for the dead load and imposed load respectively for the structural design calculations. This load factors combination is based on the Code of Practice for the Structural Use of Steel 2005, Buildings Department.

The maximum horizontal loading shall be a point load of **0.3 kN** in each case in the most unfavourable position. This requirement is based on the specification BS EN 12811-1:2003.

The maximum deflection of any decking component shall **not exceed 1/100** of the span of that decking component. This requirement is based on the specification BS1139-5:1990 HD 1000:1988 Metal scaffolding — Part 5.

Table 6.1: Summary of Code of Practices and Standards.

Type	Standard	Clause	Requirements
Load Factors	Guidelines on the Design and Construction of Bamboo Scaffolds, Building Department	C. 1	The load factor used should be 1.5 for dead and live loads and 1.4 for wind load. The wind load can be deduced from a wind speed of a 2-years return period or the design life of the bamboo scaffolds whichever is the greater with appropriate use of wind coefficients for shape and location from the Code of Practice on Wind Effects in Hong Kong 2004.
	BS EN 12811-1:2003 Temporary works equipment — Part 1: Scaffolds — Performance requirements and general design	10.3.2 And 10.3.2.2	**Partial safety factors, γ_F** Except where stated otherwise, the partial safety factors, γ_F, shall be taken as follows: Ultimate limit state - γ_F = 1.5 for all permanent and variable loads - γ_F = 1.0 for accidental loads Serviceability limit state - γ_F = 1.0 **Partial safety factors for resistance γ_M** For the calculation of the design values of the resistances of steel or Aluminium components the partial safety factor, γ_M, shall be taken as 1.1. For components of other materials the partial safety factor, γ_M, is to be taken from relevant standards. For the serviceability limit state, γ_M, shall be taken as 1.0.

	BS EN 1004:2004 Mobile access and working towers made of prefabricated elements — Materials, dimensions, design loads, safety and performance requirements	11.3.2	**11.3.2.1 Partial safety factors for actions, γ_F** Except when stated otherwise, the partial safety factor, γ_F, shall be taken as follows: a) ultimate limit state γ_F = 1.5 for all permanent and variable loads; γ_F = 1.0 for accidental loads; b) serviceability limit state γ_F = 1.0 **11.3.2.2 Partial safety factors for material resistances, γ_M** For the calculation of the design values of the resistance of steel or Aluminium components the partial safety factor, γ_M, shall be taken as 1.1. For components of other materials the partial safety factor, γ_M, shall be taken from relevant documents. For the serviceability limit state, γ_M, shall be taken as 1,0.
Deflection Limit	BS1139-5:1990 HD 1000:1988 Metal scaffolding — Part 5: Specification for materials, dimensions, design loads and safety requirements for service and working scaffolds made of prefabricated elements	5.2.7	The maximum deflection of any decking component shall not exceed 1/100 of the span of that decking component.
Deflection Limit	BS EN 12811-1:2003 Temporary works equipment — Part 1: Scaffolds — Performance requirements and general design	6.3	When subjected to the concentrated loads specified in Table 3, columns 3 and 4 the elastic deflection of any platform unit shall not exceed 1/100 of its span. Furthermore, when the appropriated concentrated load is applied, the maximum deflection difference between adjacent loaded and unloaded platform units shall not exceed 25mm.

<table>
<tr><td>Testing</td><td>Guidelines on the Design and Construction of Bamboo Scaffolds, Building Department</td><td>C. 1</td><td>Where the recommendations for typical scaffolding systems in these guidelines are not followed, the bamboo scaffolds should be justified by full scale tests or designed by a performance-based design approach.</td></tr>
<tr><td rowspan="3">Imposed Loads</td><td>Guidelines on the Design and Construction of Bamboo Scaffolds, Building Department</td><td>5.1 (h)</td><td>The safe working loads for individual couplers and fittings should comply with BS5973 or other equivalent national/international standards or provisions.</td></tr>
<tr><td>Code of Practice for Bamboo Scaffolding Safety, Labour Department</td><td>4.1</td><td>2kPa or 2kN over any square with a 300mm side and at the end portion of a cantilever (For General building work, purpose including brickwork, window and mullion fixing, rendering, plastering)</td></tr>
<tr><td>BS EN 12811-1:2003 Temporary works equipment — Part 1: Scaffolds — Performance requirements and general design</td><td>Table 3</td><td>As shown Below
Table 3 — Service loads on working areas (see also 6.2.2)
<table>
<tr><td rowspan="2">Load class</td><td rowspan="2">Uniformly distributed load q_1 kN/m²</td><td rowspan="2">Concentrated load on area 500 mm x 500 mm F_1 kN</td><td rowspan="2">Concentrated load on area 200 mm x 200 mm F_2 kN</td><td colspan="2">Partial area load</td></tr>
<tr><td>q_2 kN/m²</td><td>Partial area factor a_p [1]</td></tr>
<tr><td>1</td><td>0,75 [2]</td><td>1,50</td><td>1,00</td><td>---</td><td>---</td></tr>
<tr><td>2</td><td>1,50</td><td>1,50</td><td>1,00</td><td>---</td><td>---</td></tr>
<tr><td>3</td><td>2,00</td><td>1,50</td><td>1,00</td><td>---</td><td>---</td></tr>
<tr><td>4</td><td>3,00</td><td>3,00</td><td>1,00</td><td>5,00</td><td>0,4</td></tr>
<tr><td>5</td><td>4,50</td><td>3,00</td><td>1,00</td><td>7,50</td><td>0,4</td></tr>
<tr><td>6</td><td>6,00</td><td>3,00</td><td>1,00</td><td>10,00</td><td>0,5</td></tr>
<tr><td colspan="6">[1] See 6.2.2.4
[2] See 6.2.2.1</td></tr>
</table></td></tr>
<tr><td rowspan="2">Horizontal Load</td><td>BS EN 12811-1:2003 Temporary works equipment — Part 1: Scaffolds — Performance requirements and general design</td><td>6.2.5.2</td><td>All components of the side protection, except toe boards, shall be designed to resist a horizontal point load of 0.3 kN in each case in the most unfavorable position. This load may be distributed over an area of maximum 300 mm×300 mm, for example when applied to the grid of a fencing structure. For toe boards, the horizontal point load is 0.15 kN.</td></tr>
<tr><td>Code of Practice for Metal Scaffolding Safety, Labour Department</td><td>5.4.1</td><td>Engineering considerations
(b) The minimum lateral loads should be taken as the greater of:
(i) the most adverse combination of the above lateral loads; or
(ii) 2.5% of the vertical loads taken as acting at the points of contact between the vertical loads and the supporting false work.</td></tr>
</table>

6.3.2 *Weight and Strength*

The total weight of RDP Prototype I is 95.12 kg as shown in Table 6.2. It can be seen from the table that the weight of the steel frames contributed to over 60% of the total weight of the RDP. Therefore, it is believed a lighter structural material should be used to fabricate the frames in order to reduce the weight of the RDP.

Table 6.2: Weight Summary of RDP Prototype I.

Item	Component	Weight (kg)	Materials	%
1	Platforms	16.7	Wood	17.6%
2	Toe boards	5	Wood	5.3%
3	Tie	1.58	G. Steel	1.7%
4	Handrails	11.24	G. Steel	11.8%
5	U shaped frame (U-frame)	17.96	Structural Steel	18.9%
6	Triangle frame (Frame B)	20	Structural Steel	21.0%
7	Base support	22.64	Structural Steel	23.8%
Total		**95.12**		100.0%

In RDP Prototype II, there were two versions of triangular frames, one made of aluminium and the other made of Structural Steel Grade S355. At the beginning of this project, aluminium was proposed to be the materials of the triangular frames for RDP Prototype II because the weight of the aluminium alloy is less than 1/2 of that of structural steel. Two (2) aluminium triangular frames were fabricated and were shown in the 2nd Task Force Meeting on 26th June 2007. However, the task force members pointed out that aluminium is less durable when comparing with structural steel. Therefore, a structural steel triangular frame with smaller section size but higher material strength was proposed afterwards.

6.3.2.1 RDP Prototype II with Aluminium Triangular Frames

Tables 6.3 and 6.4 summarize the materials used in the two prototypes and weight of each structural component. Table 6.5 summarizes the materials properties of Grade S355 structural steel and aluminium alloy 6063 T5. The reduction of weight is a primary concern for front-line workers using the RDP since the triangular frames have to be installed outside the building. Although the design strength (p_y) of the aluminium alloy is substantially lower than that of structural steel, it is still sufficient to support the loading safely.

Material for the U-frames and the Base-supports of RDP Prototype II is Grade S355 structural steel. It was found from the analysis that the U-frames rigidity affects the platform deformation significantly hence, it was subsequently decided that structural steel would be used to fabricate these elements.

Table 6.3: Weight Summary of RDP Prototype I.

Structural Components	Weight (kg)	Materials
U-frames (2 Nos.)	17.96	Structural Steel, Grade 43
Triangle frames (2 Nos.)	20	Structural Steel, Grade 43
Base supports (2 Nos.)	22.64	Structural Steel, Grade 43
Total Weight (kg)	**60.6**	

Table 6.4: Weight Summary of RDP Prototype II (Aluminium).

Structural Components	Weight (kg)	Materials
U-frames (2 Nos.)	16	Structural Steel, Grade S355
Triangle frames (2 Nos.)	10.8	Aluminium Alloy, 6063T5
Base supports (2 Nos.)	14.4	Structural Steel, Grade S355
Total Weight (kg)	**41.2**	

Table 6.5: Materials Properties.

Properties	Structural Steel, Grade S355	Aluminium Alloy, 6063T5
Yield Strength, p_y (MPa)	355	110
Density (kg/m^3)	7860	2710
Modulus of elasticity (MPa)	205000	70000

6.3.2.2 RDP Prototype II with Structural Steel Triangular Frames

Tables 6.3 and 6.6 summarize the materials used in the two prototypes and weight of each structural component. The triangular frames for RDP Prototype II were made of 25×25×3 mm SHS section of Grade S355 structural steel. With this higher steel grade (the steel grade used for RDP Prototype I was Grade 43), the size of the new section could be reduced and hence, the weight of the triangular frames for RDP Prototype II was significantly reduced when compared with that of the RDP Prototype I. It should be noted that this weight reduction of using the SHS section was similar to that of using the aluminium alloy for the triangular frames. Hence, it was believed that the use of the 25×25×3 mm SHS section of Grade S355 structural steel would be a more desirable choice of material for the RDP since the strength of the material is higher and the cost is relatively low when compared with that of aluminium alloy.

Table 6.6: Weight Summary of RDP Prototype II.

Structural Components	Weight (kg)	Materials
U-frames (2 Nos.)	16.92	Structural Steel, Grade S355
Triangle frames (2 Nos.)	10.2	Structural Steel, Grade S355
Base supports (2 Nos.)	15.32	Structural Steel, Grade S355
Total Weight (kg)	**42.44**	

6.4 Testing Program of RDP Prototype I

The test information of RDP Prototype I is summarized in Table 6.7. It can be seen from the table that three types of tests, namely; performance test (uniformly distributed load), performance test (point load) and evaluation test (point load) were conducted on RDP Prototype I in order to examine its performance under factored loads condition (performance tests) and the strength and behaviour of the triangular frame (evaluation test).

Table 6.7: Experimental Tests Summary.

No.	Test Type (Specimen)	Loading Type	Date
1.	Performance Test (Specimen 1)	Uniformly Distributed Load by placing sand bags on to the RDP platform	15th February 2007
2.	Performance Test (Specimen 1)	Point Load applied on to the RDP within a 300×300 mm^2 area by using a hydraulic jack	27th February 2007
3.	Evaluation Test (Specimen 2)	Uniformly Distributed Load (point load from hydraulic jack which is distributed to Frame B through an I beam	7th March 2007

6.4.1 Objectives

The objectives of the RDP Prototype I testing are:

1. To determine the structural performance of the RDP Prototype I.
2. To obtain experimental results to validate the numerical model of the RDP Prototype I.

6.4.2 Description of Testing Program

There were two types of tests conducted, these included performance and evaluation tests as discussed above.

The performance tests were used to verify the structural capacity of the RDP Prototype I in supporting the loading required according to the local scaffolding standards (reference). The loadings used in the tests were carried out according to the "General purpose duty" category of the Code of Practice for Bamboo Scaffolding System as shown in Table 6.8. A load factor equal to 1.5 was used according to the Guidelines on the Design and Construction of Bamboo Scaffolds (Building Department, 2006). Therefore the maximum loadings used were calculated to be 3 kPa and 3 kN for the distributed load and point load tests respectively.

Table 6.8: Minimum Imposed Loads for Bamboo Scaffolding (From Code of Practice for Bamboo Scaffolding Safety).

Code of Practice for Bamboo Scaffolding Safety

Minimum Imposed Loads			
Duty	Use of platform	Distributed load on platform	Concentrated load to be applied on plan over any square with a 300mm side and at the end portion of a cantilever
Inspection and very light duty	Inspection, painting, stone cleaning, light cleaning and access	0.75 kN/m²	2 kN
Light duty	Plastering, painting, stone cleaning, glazing and pointing	1.5 kN/m²	2 kN
General purpose	General building work including brickwork, window and mullion fixing, rendering, plastering	2 kN/m²	2 kN
Heavy duty	Blockwork, brickwork, heavy cladding	2.5 kN/m²	2 kN
Masonry or special duty	Masonry work, concrete blockwork and very heavy cladding	3 kN/m²	2 kN

The evaluation test was conducted to evaluate the strength and behaviour of the steel frame (made up of the U-frame and the triangular frame), as shown in Figure 6.5b. The numerical model of the RDP Prototype I can be validated using the experimental results from this test. In addition, the strength of this important supporting unit of the RDP could be demonstrated by the test.

6.4.2.1 Test Specimens

Specimen 1 – Full RDP Prototype I, for carrying out the performance tests as shown in Figure 6.5a.

Specimen 2 – A single unit (U-frame and triangular frame) as shown in Figure 6.5b, for carrying out the evaluation test of a single steel frame.

The steel members in the U-frame and the triangular frame were made of Grade 43 steel with SHS sections of size 40×40×3 mm as shown in Figure 6.6.

(a)

(b)

Figure 6.5: (a) Specimen 1–RDP Prototype I and (b) Specimen 2–Single Unit (A set of U-frame and Triangular-Frame).

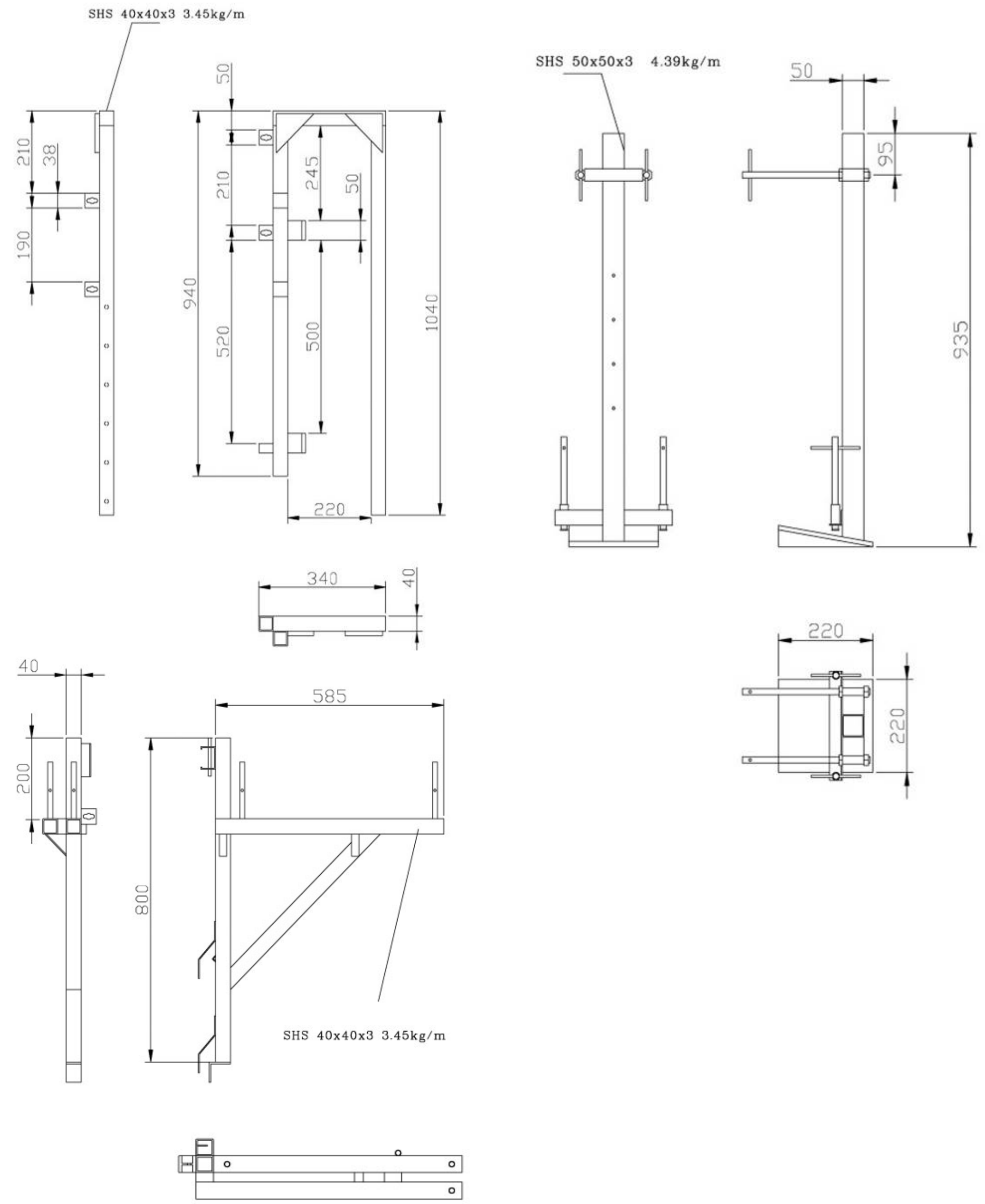


Figure 6.6 Dimensions of Steel Frames

6.4.2.2 Test Setup and Instrumentations

A full scale typical window frame mounted on a brick wall was constructed in the laboratory of the Industrial Centre at The Hong Kong Polytechnic University for the testing. Photos and schematics of the test setup are shown in Figures 6.7, 6.8 and 6.9. As can be seen from Figure 6.7, the uniformly distributed load of approximate 3 kPa was imposed onto the RDP using sand bags (Test No. 1). For the point load of 3 kN acting over an area of 300 mm$\times$300 mm on the platform, a hydraulic loading jack system was used (Test No. 2). The jack was placed on the loading area with a load cell sitting on top. In turn, the load cell was bore against a reaction frame which was bolted down to the floor as shown in Figure 6.8. For the evaluation test on the U-frame and the triangular frame, a distributing beam was used to spread the load from the loading jack to Frame B as shown in Figure 6.9 (Test No. 3).

The applied load was recorded using a load cell for the testing with a point load. For the uniformly distributed load case, sand bags were weighed and placed onto the platform. The deformation of the steel frame was recorded by strain gauges at a number of critical locations as shown in Figure 6.10. Dial gauges and Linear Variable Differential Transformers (LVDT) were employed to record the movement and deflection of the RDP as shown in Figure 6.11. The readings from the strain gauges, the LVDTs and the load cell were recorded continuously using a data acquisition system. Photos were also taken during testing.

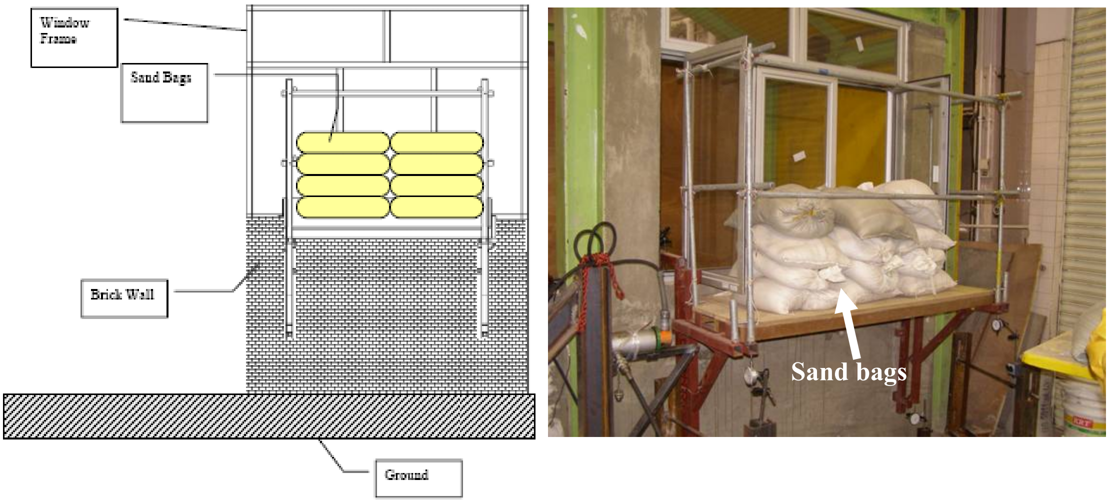


Figure 6.7: Test Setup of Specimen 1 for the Performance Test (Test No.1).

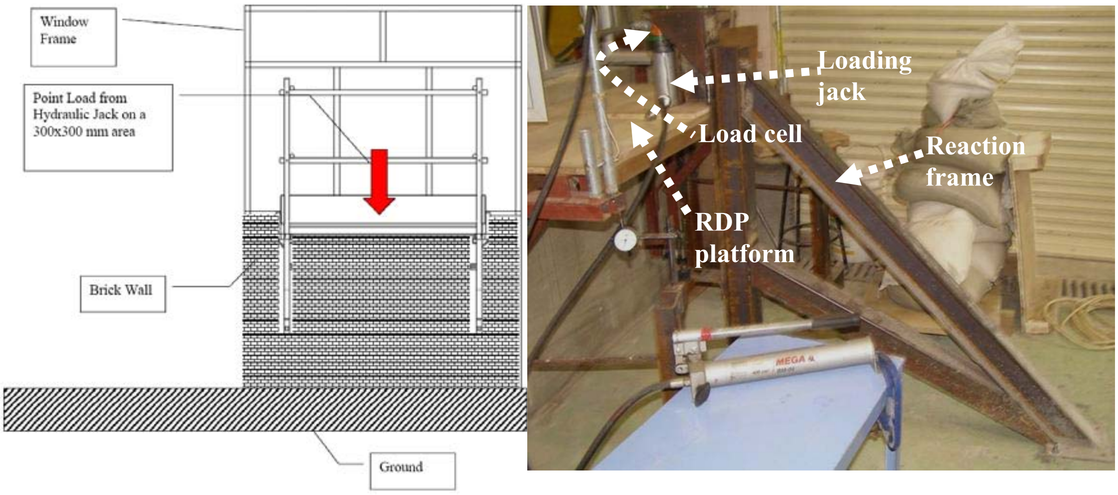


Figure 6.8: Test Setup of Specimen 1 for the Performance Test (Test No.2).

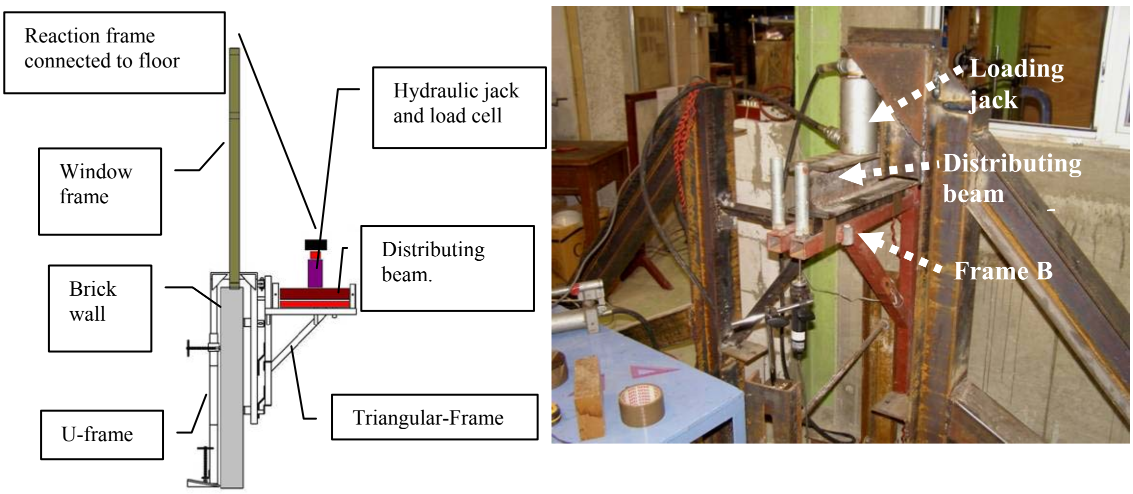


Figure 6.9: Test Setup of Specimen 2 for the Evaluation test (Test No. 3).

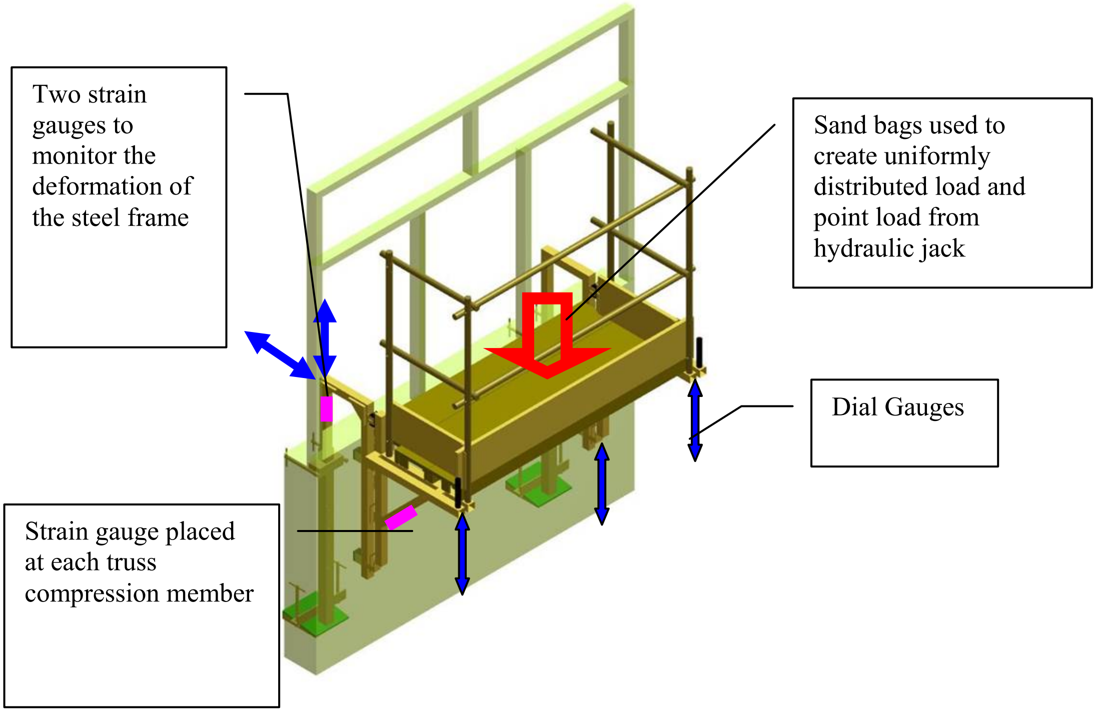


Figure 6.10: Positions of Instrumentations of Specimen 1 for the Performance Test (Test No. 1 and 2).

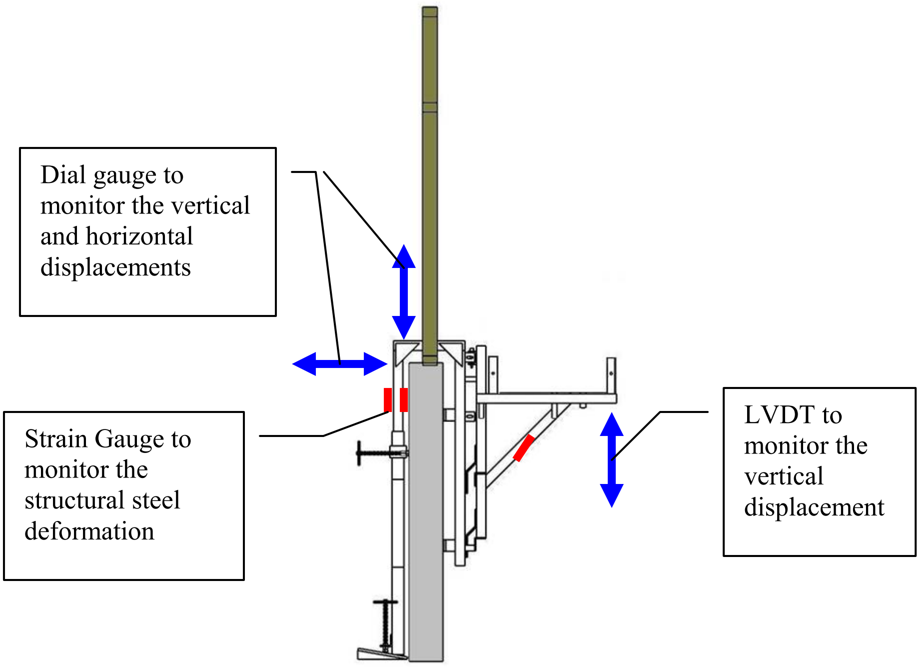


Figure 6.11: Positions of Instrumentations of Specimen 2 for the Evaluation Test (Test No. 3).

6.4.2.3 Test Procedures

In general, the test procedures were similar for all the tests. The RDP Prototype I (Test 1 and 2) and the U-frame and the triangular frame (Test 3) were properly sat before load was applied. The instrumentation was checked and all the readings in the load cell, the strain gauges and the LVDT were initialized. The loads were then applied incrementally to the specimens so that the dial gauge readings could be recorded and the behaviour of the test specimen could be observed. Readings of the load cell, the strain gauges and the LVDT were recorded continuously during the entire loading process. Loading was stopped when the applied load reached the required load level for the performance test. However, the evaluation test was terminated before yielding of the steel frames was observed.

6.4.2.4 Test Results

6.4.2.4.1 General

Table 6.9 summarizes the maximum loads and the corresponding vertical displacements at the tip of the specimens. It can be seen from the table that the RDP Prototype I satisfied the required loading according to the minimum imposed loads for bamboo scaffolding (Code of Practice for Bamboo Scaffolding Safety, 2001) with the appropriate load factor of 1.5. The deflection at the tip was considered small even with a factored load condition. The evaluation test results indicated that the steel frames (A and B) were capable to support higher loading. The maximum load reached in Test 3 was 11.28 kN (corresponds to 26.23 kN/m). This maximum load corresponded to the load level at which the strain at U-frame was very close to yield. Further discussion on the strain gauge readings will be presented in the later section.

Table 6.9: Summary of Test Results.

Test No.	**Max. Applied Load**	**Vertical Displacement (mm)**	**Deflection to Span (Span = 585mm)**
1	3.29 kPa	1.61	1/363
2	3.18 kN	2.65	1/221
3	11.28 kN (equivalent to 26.23 kN/m)	22.75	1/26

6.4.2.4.2 Load Deflection Behaviour

Figures 6.12, 6.13 and 6.14 show the load versus deflection plots for all the tests. It can be seen from Figure 6.12 and 6.13 that relatively linear load deflection behaviour was recorded for Test 1 and 2. In particular, the deflection readings for position 3 and 4 were quite similar indicating that the steel frames on each end of the RDP shared approximately equal load. Movement of U-frame at the top (position 1) was also observed. This movement was caused by the moment generated by the platform loading. The maximum deflections for these tests were all below 3 mm. Based on these performance test results, it can be seen that the RDP Prototype I is structurally sound and adequate according to the requirements of the local codes and standards.

Figure 6.11 shows the load versus displacement plot of Test 3. In the initial loading stage (ignoring the curve before 0.5 kN due to sitting of the specimen) the load deflection curve was relatively linear. However, when the applied reached about 8 kN, the curve started to turn nonlinear. This might be caused by the bending of the steel member in U-frame. Although the strain readings at this loading stage indicated that the steel frame was still in the elastic stage, it is believed that yielding might have occurred in other locations of the frame.

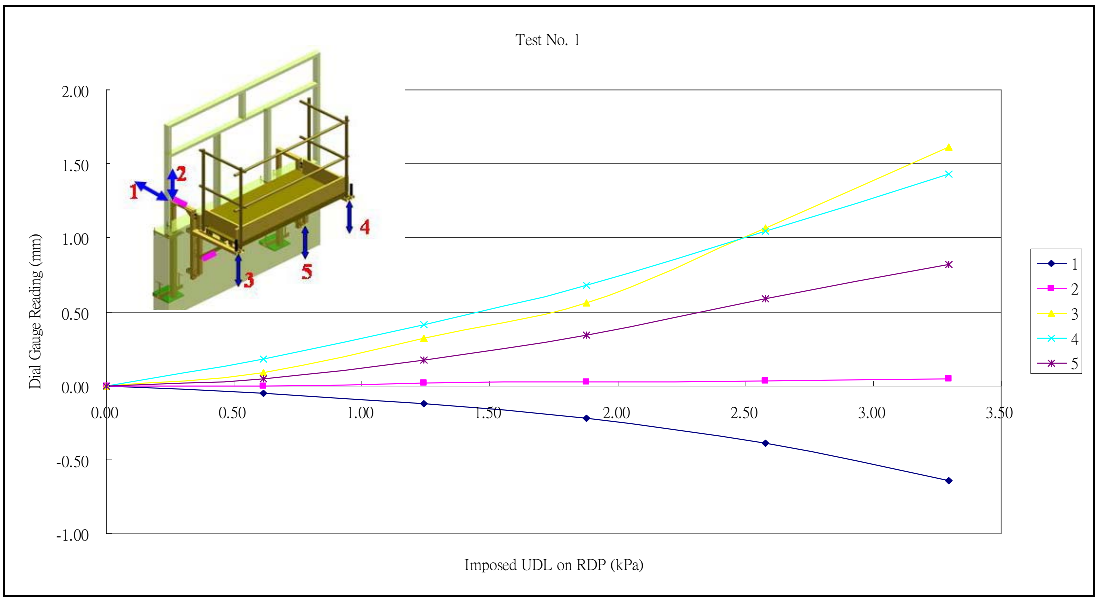


Figure 6.12: Plot of Distributed Load vs Deflection of Test 1.

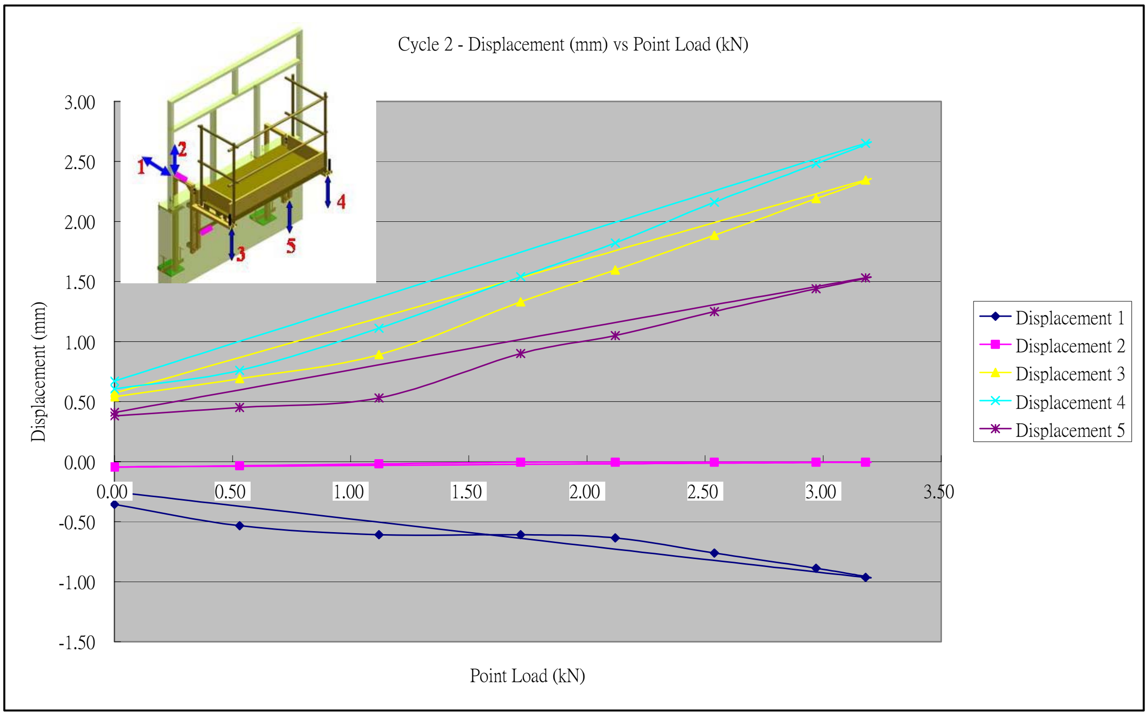
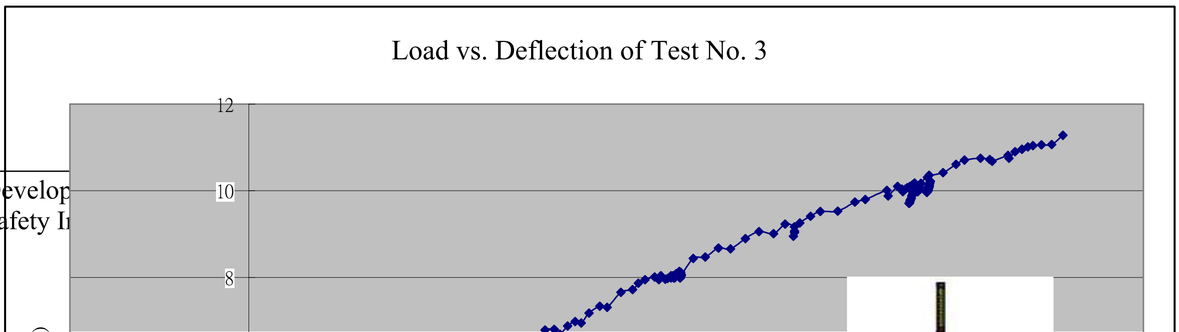


Figure 6.13: Plot of Point Load vs. Deflection of Test 2.



6.4.2.4.3 Strain Gauge Results

The strain gauges readings for Test 1 and 2 were too small to have any significant indication on the strain values. Therefore, these readings are not discussed in this progress report.

Figure 6.15 shows the load versus strain readings plot of Test. 3. The results show that the strain readings at strain gauge #2 varied linearly with respect to the applied load. It should be noted that strain gauge #2 was located at the diagonal member of Frame B. The strain readings also indicated that the diagonal member was under compression as expected. For strain gauge #0 and #1, these gauges were located on the vertical member of U-frame as indicated in the inset of Figure 6.15. In general, the readings from these 2 strain gauges illustrated that the member was subjected to a combined axial load and bending moment. Nonlinear load vs. strain behaviour was observed due to this combined load effect. As mentioned above, the strain gauge readings were all below the yield strain of the material.

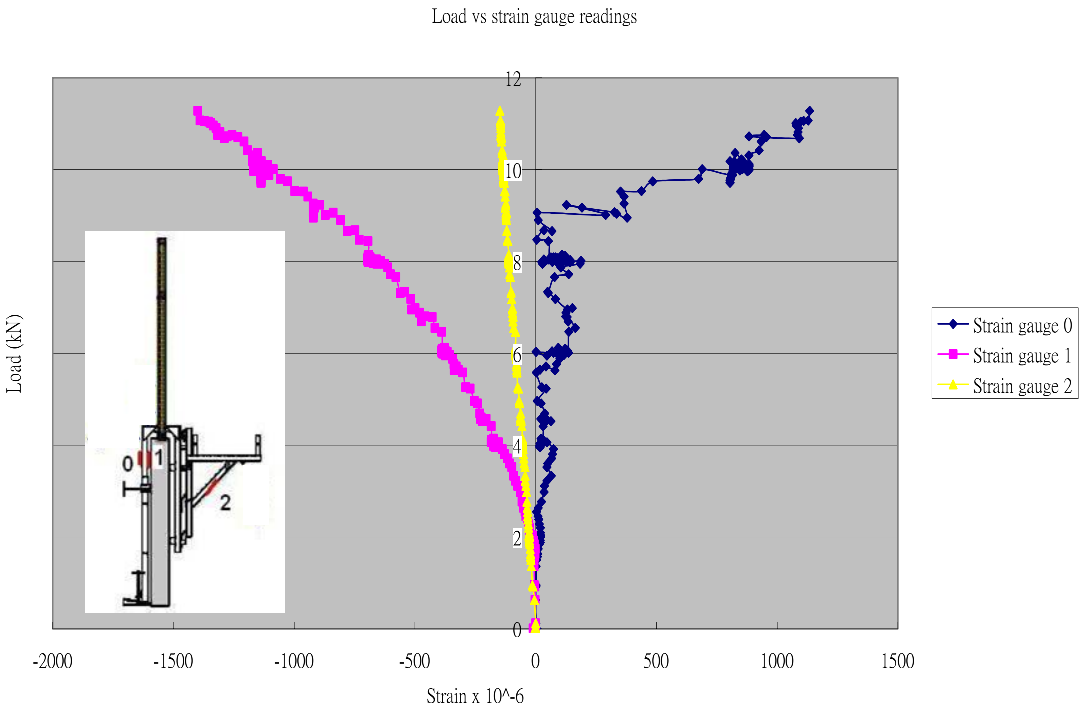


Figure 6.15: Plot of Point Load vs. Displacement of Test 3.

6.4.3 Summary

1. Based on the test results, it can be seen that the RDP Prototype I is able to support an imposed load as stipulated in the "Code of Practice for Bamboo Scaffolding Safety" under the "General Purpose duty" category. The maximum deflections recorded during the performance testing were all below 3 mm.

2. An evaluation test was conducted to further examine the load carrying capacity of the steel frames. The test results showed that the steel frame was able to support a maximum load of 11.28 kN (26.23 kN/m) with a corresponding maximum deflection of 22.75mm. This maximum load was recorded prior to yielding of the material based on the strain readings.

3. The total weight of the RDP was 95.12 kg. The steel frames contributed to over 60% of the weight of the RDP. Therefore, a lighter structural material should be used to fabricate the structural frames.

6.5 Testing Program of RDP Prototype II

The test information of RDP Prototype II is summarized in Table 6.10. Similar to the tests for the RDP Prototype I, both the performance test and the evaluation test were conducted on RDP Prototype II. However, an additional test (point loading) on the railing panel was conducted to examine the deflection characteristics of the railing system. The point load applied on the railing panel was based on the requirement of BS EN 12811-1:2003 for scaffolds. The railing panel should be strong enough to support the horizontal load due to the worker working on the platform and at the same time the deflection of the railing panel should be limited to an acceptable level.

Table 6.10: Experimental Tests Summary of Prototype II.

No.	Test Type (Specimen)	Loading Type	Date
1.	Performance Test (Specimen 3)	Uniformly Distributed Load by placing sand bags on to the RDP platform	12th September 2007
2.	Performance Test (Specimen 3)	Point Load applied on to the RDP within a 300×300 mm^2 area by using a hydraulic jack	13th September 2007
3.	Performance Test (Specimen 3)	Point Load applied on to the mid point of the RDP Hand Rail by using a hydraulic jack	14th September 2007
4.	Evaluation Test (Specimen 4)	Uniformly Distributed Load (point load from hydraulic jack which is distributed to Triangular frame through an I beam	14th September 2007

6.5.1 Objectives

The objectives of the RDP Prototype II testing are:

3. To determine the structural performance of the RDP Prototype II.
4. To obtain experimental results to validate the numerical model of the RDP Prototype II.

6.5.2 *Description of Testing Program*

Similar to the tests of RDP Prototype I, two types of tests conducted including the performance and the evaluation tests were conducted as discussed above. However, an additional test (horizontal load) on the railing panel was included in the performance test of the RDP Prototype II.

Since the details of the tests were similar to that of the RDP Prototype I as discussed above, therefore it would not be repeated in this section. For the horizontal load test of the railing panel, a point load of 0.3 kN was applied to the railing panel to examine its deflection characteristic.

6.5.2.1 Test Specimens

Specimen 3 – Full RDP Prototype II, for carrying out the performance tests is shown in Figure 6.16a.
Specimen 4 – A single unit (U-frame and triangular frame) is shown in Figure 6.16b, for carrying out the evaluation test of a single steel frame.
The steel members in U-frame and triangular frame were made of 50×30×3mm RHS and 25×25×2.5 mm SHS with Grade S355 steel respectively as shown in Figure 6.16.

(a)

Error!

(b)

Figure 6.16: a) Specimen 1–RDP Prototype II and (b) Specimen 2–Single Unit (A set of U-frame and Triangular-Frame).

6.5.2.2 Test Setup and Instrumentations

The same window frame and brick wall constructed in the laboratory of the Industrial Centre at the Hong Kong The University was again used for the testing. Photos and schematics of the test setup are shown in Figure 6.17 to 6.20. As can be seen from Figure 6.17, a uniformly distributed load of approximate 3 kPa was imposed onto the RDP using sand bags (Test No.1). For the point load of 3 kN acting over an area of 300 mm×300 mm on the platform, a hydraulic loading jack system was used (Test 2). The jack was placed on the loading area with a load cell sitting on top. In turn, the load cell was bore against a reaction frame which was bolted down to the floor as shown in Figure 6.18. For the performance test no. 3, a horizontal point load was applied at the mid point of the top hand rail through a tied rod connected to a hydraulic jack as shown in Figure 6.19. For the evaluation test on the U-frame and the triangular frame, a distributing beam was used to spread the load from the loading jack to the triangular frame as shown in Figure 6.20 (Test 4).

The applied load was recorded using a load cell for the testing with a point load. For the uniformly distributed load case, sand bags were weighed and placed onto the platform. The deformation of the steel frame was recorded by strain gauges at a number of critical locations same as those for RDP Prototype I. Dial gauges and Linear Variable Differential Transformers (LVDT) were employed to record the movement and deflection of the RDP. The readings from the strain gauges, the LVDT and the load cell were recorded continuously using a data acquisition system. Photos were also taken during testing.

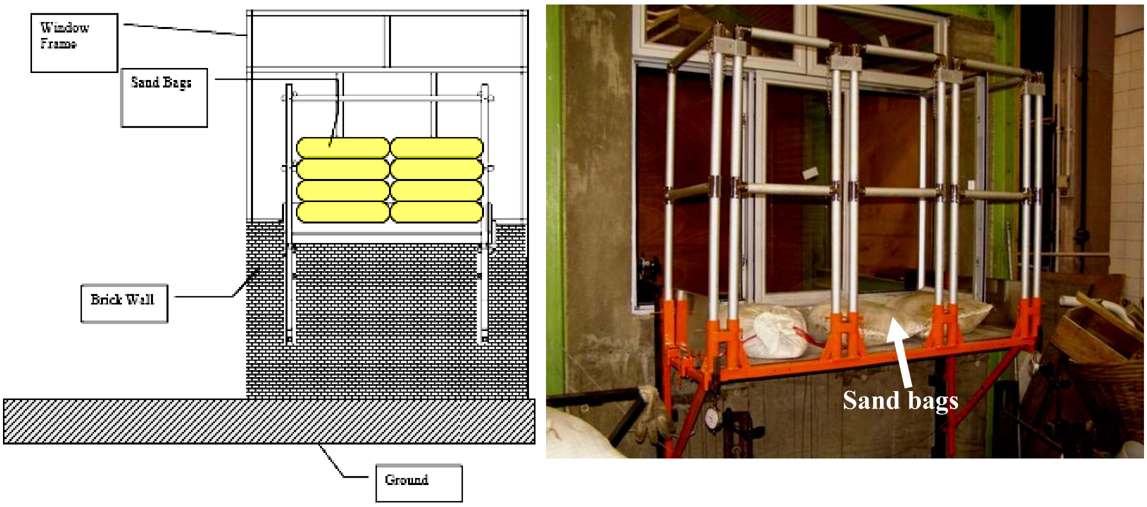


Figure 6.17: Test Setup of Specimen 3 for the Performance Test (Test No.1).

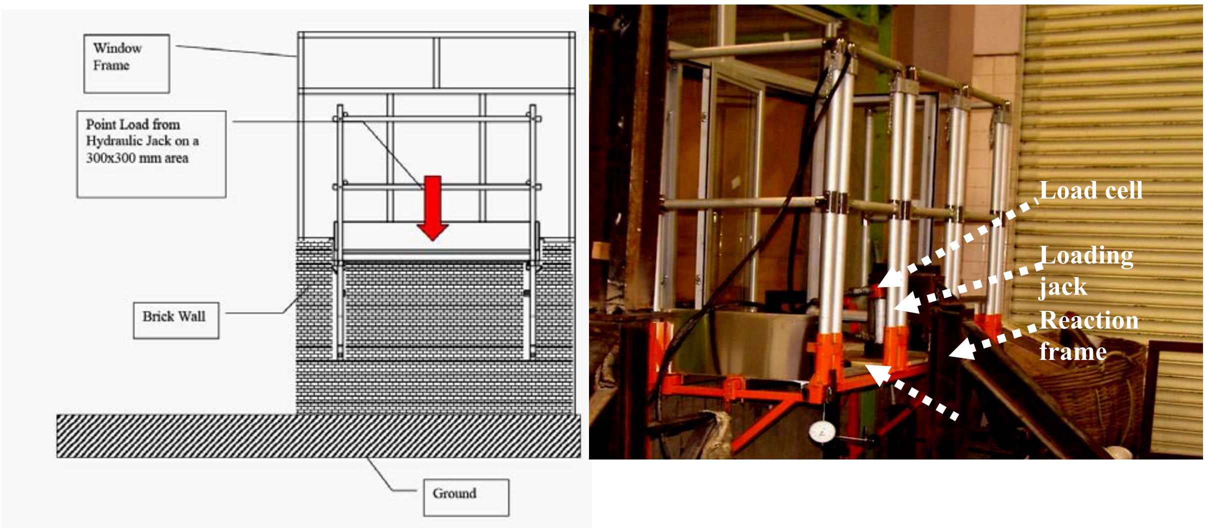


Figure 6.18: Test Setup of Specimen3 for the Performance Test (Test No.2).

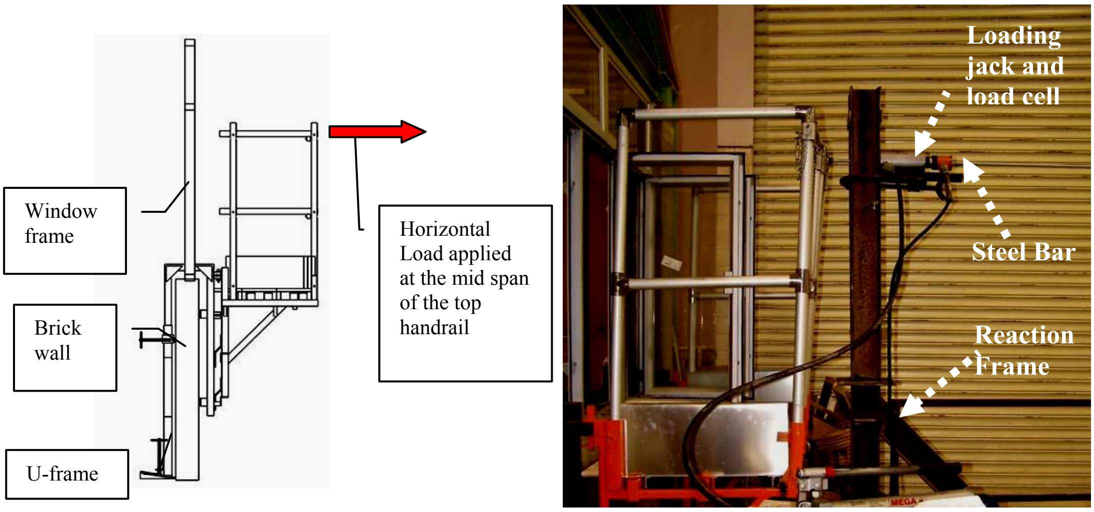


Figure 6.19: Test Setup of Specimen 3 for the Performance test (Test No. 3).

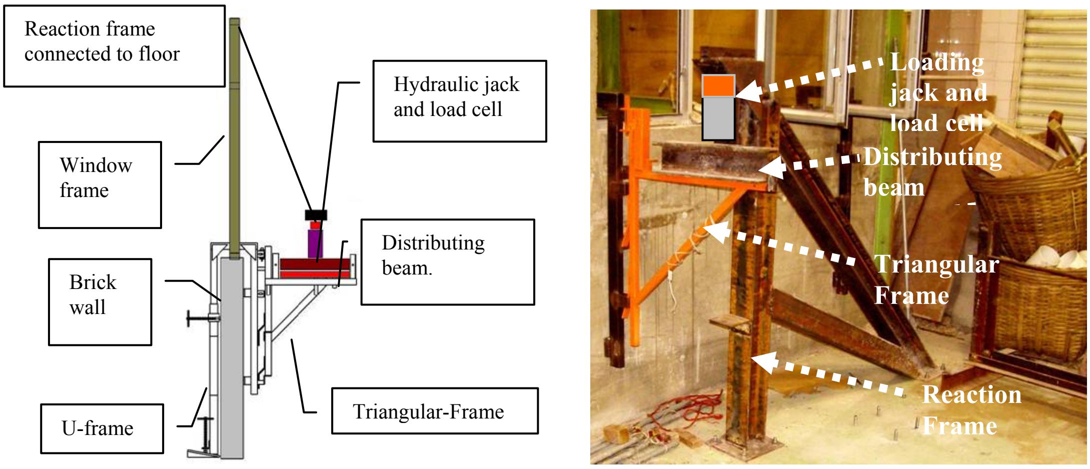


Figure 6.20: Test Setup of Specimen 4 for the Evaluation test (Test No. 4).

6.5.2.3 Test Procedures

In general, the test procedures were similar for all the tests. The RDP Prototype II was properly sat before load was applied. The instrumentation was fixed and all the readings in the load cell, the strain gauges and the LVDT were initialized. The loads were then applied incrementally to the specimens so that dial gauge readings could be recorded and the behaviour of the test specimen could be observed. Readings of the load cell, the strain gauges and the LVDT were recorded continuously during the entire loading process. Loading was stopped when the applied load reached the required load level for the performance test. However, the evaluation test was terminated before yielding of the steel frames was observed.

6.5.2.4 Test Results

<u>6.5.2.4.1 General</u>

Table 6.11 summarizes the maximum loads and the corresponding vertical displacements at the tip of the specimens. It can be seen from the table that the RDP Prototype II satisfied the required loading according to the minimum imposed loads for bamboo scaffolding (Code of Practice for Bamboo Scaffolding Safety, 2001) with the appropriate load factor of 1.5. The evaluation test results indicated that the steel frames (U-frame, triangular frame and base support) were capable of supporting higher loading. The maximum load reached in Test 3 was 11.04 kN (corresponds to 25.67 kN/m). This maximum load corresponded to the load level at which the strain at U-frame was very close to yield. Further discussion on the strain gauge readings will be presented in the later section. It can be seen that the results of RDP Prototype II were comparable to that the RDP Prototype I.

Table 6.11: Summary of Test Results of RDP Prototype II.

Test No.	**Max. Applied Load**	**Displacement 3 (mm)**	**Deflection to Span (Span = 585mm)**	**Displacement 3 (mm) from SAP2000 Results**
1	3.45 kPa	2.46	1/238	**2.33**
2	3.15 kN	3.29	1/178	**3.504**
3	0.3 kN (Horizontal load at the top of the mid-span of the railing)	70 (Horizontal displacement at the top of the mid-span of the railing)	N/A	N/A
4	11.04 kN (equivalent to 25.67 kN/m)	20.11	1/29	**21.76**

6.5.2.4.2 Load Deflection Behaviour

Figures 6.21 to 6.24 show the load versus deflection plots for all the tests. It can be seen from Figure 6.21 and 6.22 that relatively linear load deflection behaviour was recorded for Test 1 and 2. In particular, the deflection readings for position 3 and 4 were quite similar indicating that the steel frames on each end of the RDP Prototype II shared approximately equal load. Movement of U-frame at the top (position 1) was also observed. This movement was caused by the moment generated by the platform loading. Figure 6.23 shows the load deflection behaviour of the hand rails in Test 3. The figure shows that the hand rails of the RDP Prototype II could support a 0.46 kN horizontal load which is higher than the load requirement of 0.3 kN. However, a significant movement of the members of the railing panel was recorded. The test results illustrated that the railing panels moved approximately 70 mm and 90 mm horizontally at a load of 0.3 kN and 0.46 kN, respectively. It should be noted that there was about 40 mm movement of the railing panels with close to zero applied load as shown in the figure. This indicated that the fitting between the railing panels and corresponding support unit was loose which permitted such a large “free movement”. If this “free movement” was excluded (by better fitting), the actual deflection of the railing panels would be around 30 mm for the applied load of 0.3 kN. It is believed that this magnitude of deflection would be acceptable for a temporary working platform.

Figure 6.24 shows the load versus displacement plot of Test 4. The load deflection curve was relatively linear during the entire loading. This might indicate that the steel frame was still in the elastic stage.

The maximum deflections for Tests No. 1 and 2 were all below 4 mm. Although a significant horizontal movement was recorded for the railing panel during the horizontal load test, it is believed that a major part of this movement could be eliminated by proper fitting of the railing panels to the corresponding supporting unit. Based on these performance test results, it can be seen that the RDP Prototype II is structurally sound and adequate according to the requirements of the local codes and standards.

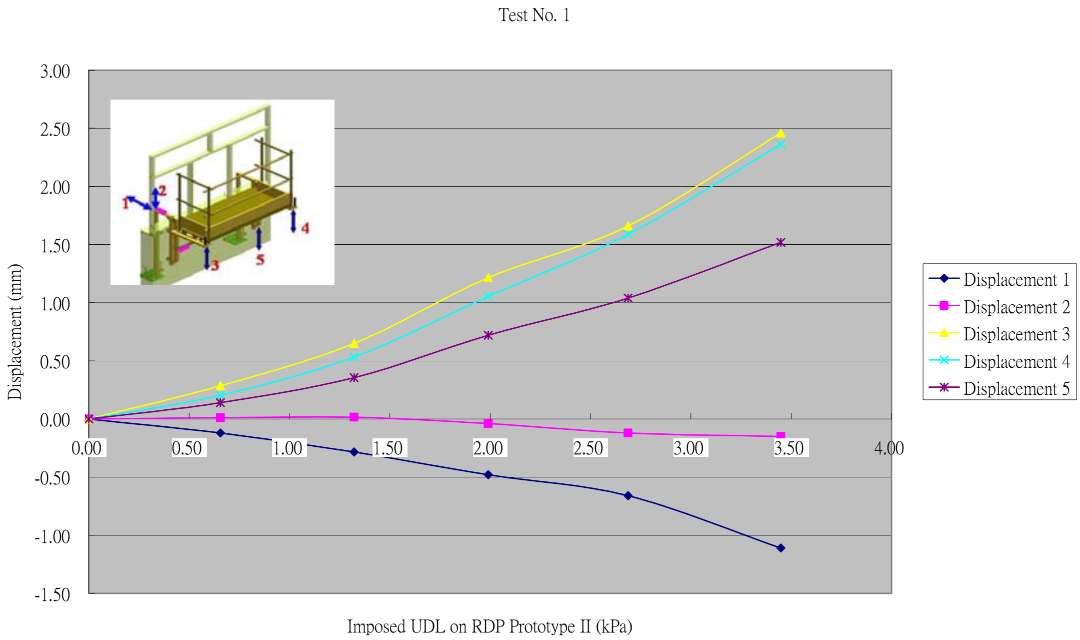


Figure 6.21: Plot of Distributed Load vs Deflection of Test No. 1.

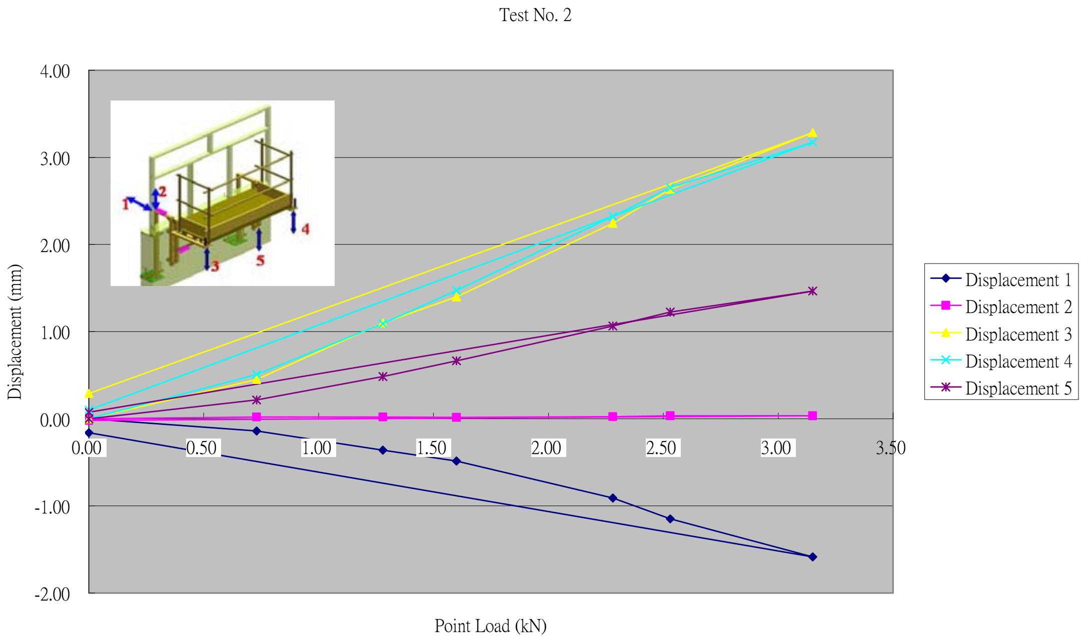


Figure 6.22: Plot of Point Load vs Displacements of Test No.2.

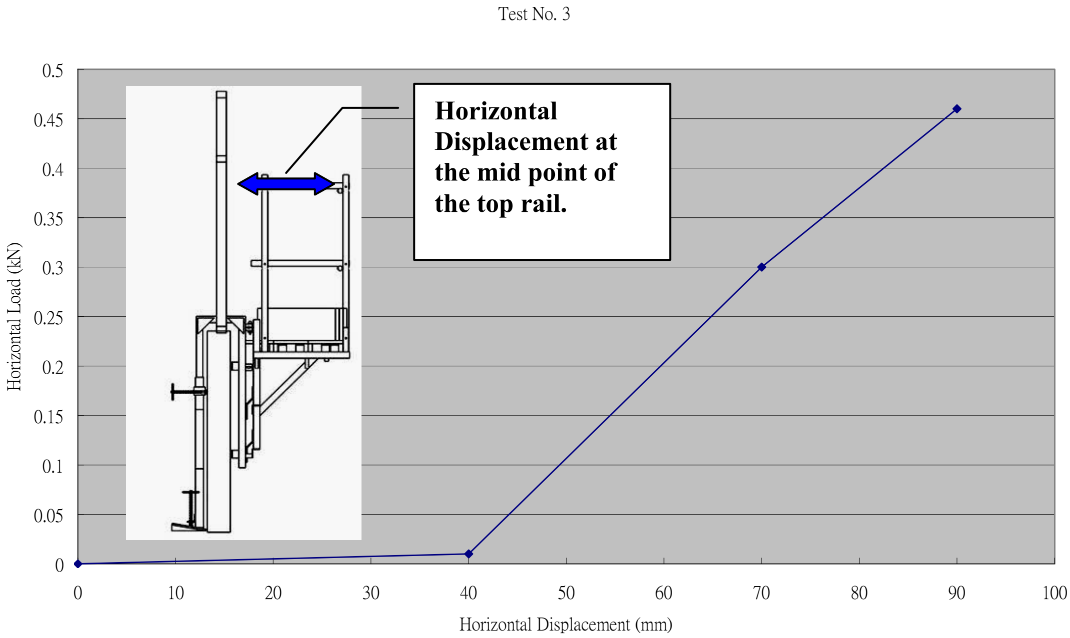


Figure 6.23: Plot of Horizontal Point Load vs Displacement Test No. 3.

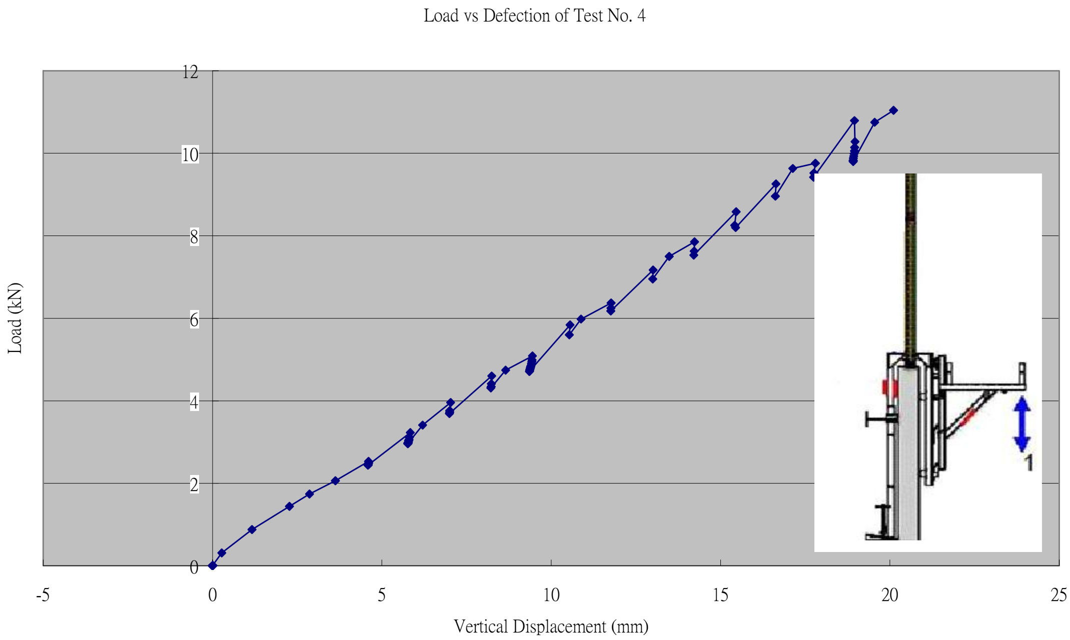


Figure 6.24: Plot of Point Load vs Deflection of Test 4.

6.5.2.4.3 Strain Gauge Results

The strain gauges readings for Test 1 and 2 were too small to have any significant indication on the strain values. Therefore, these readings are not discussed.

Figure 6.25 shows the load versus strain readings plot of Test. 4. The results show that the strain readings at strain gauge #2 varied linearly with respect to the applied load. It should be noted that strain gauge #2 was located at the diagonal member of triangular frame. The strain readings also indicated that the diagonal member was under compression as expected. For strain gauge #0 and #1, these gauges were located on the vertical member of U-frame as indicated in the inset of Figure 6.25. In general, the readings from these 2 strain gauges illustrated that the member was subjected to a combined axial load and bending moment. As mentioned above, the strain gauge readings were all below the yield strain of the material.

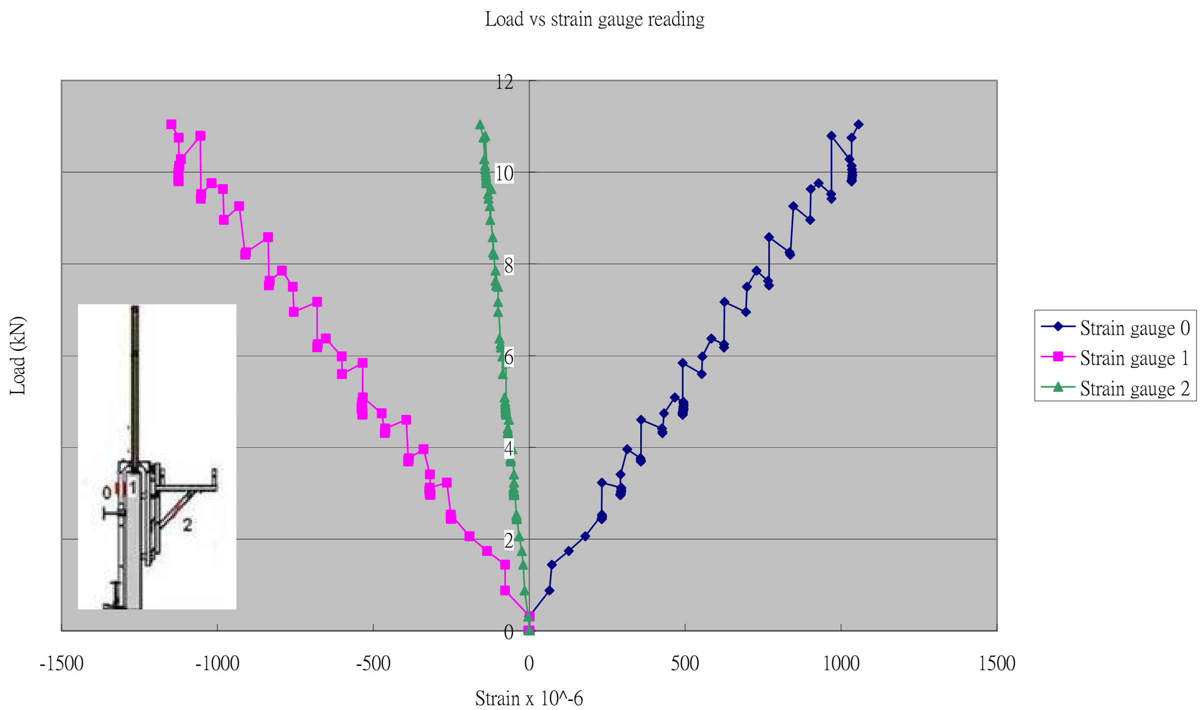


Figure 6.25: Plot of Point Load vs Displacement of Test 4.

6.5.3 Summary of Testing RDP Prototype I

1. Based on the test results, it can be seen that the RDP Prototype II is able to support an imposed load as stipulated in the “Code of Practice for Bamboo Scaffolding Safety” under the “General Purpose duty” category. The maximum deflections recorded during the performance testing were all below 4 mm.
2. Although a significant horizontal movement (70 mm for a load of 0.3 kN and 90 mm for a load of 0.46 kN) was recorded for the railing panel during the horizontal load test, it is believed that a major part of this movement could be eliminated by proper fitting of the railing panels to the corresponding supporting unit.
3. An evaluation test was conducted to further examine the load carrying capacity of the steel frames. The test results showed that the steel frame was able to support a maximum load of 11.04 kN (25.67 kN/m) with a corresponding maximum deflection of 20.11mm. This maximum load was recorded prior to yielding of the material based on the strain readings.

6.6 Numerical Analysis of RDP Prototype I

6.6.1 SAP2000 Model of RDP Prototype I

The model of RDP Prototype I was developed according to test with uniformly distributed load, as shown in Figure 6.26. There were two sets of U-frame and triangular frame supporting the platform loading. In the SAP2000 model, one set of U-frame and triangular frame was modelled. The Base-Support was not modelled in the analysis. Instead, a pin support was assigned at the bar location of the Base-Support, as shown in Figure 6.27(a), to provide vertical and horizontal reactions. This was validated by the test results, as there was no horizontal movement observed in the base supports during the test. Two rollers were assigned at the U-frame, as shown in Figure 6.27, as the reactions provided from the wall. The frame elements in SAP2000 were used to model the RDP structural elements. The size of all the elements was 40×40×3 mm SHS, with Grade 43 steel. The elastic modulus of 205×10^{3} MPa, was adopted as suggested in BS5950: Part 1: 2000. Loading assigned on the top of the triangular frame was the same as the sand bags loading of 2.997 kN. The SAP2000 model of RDP Prototype I is shown in Figure 6.28.

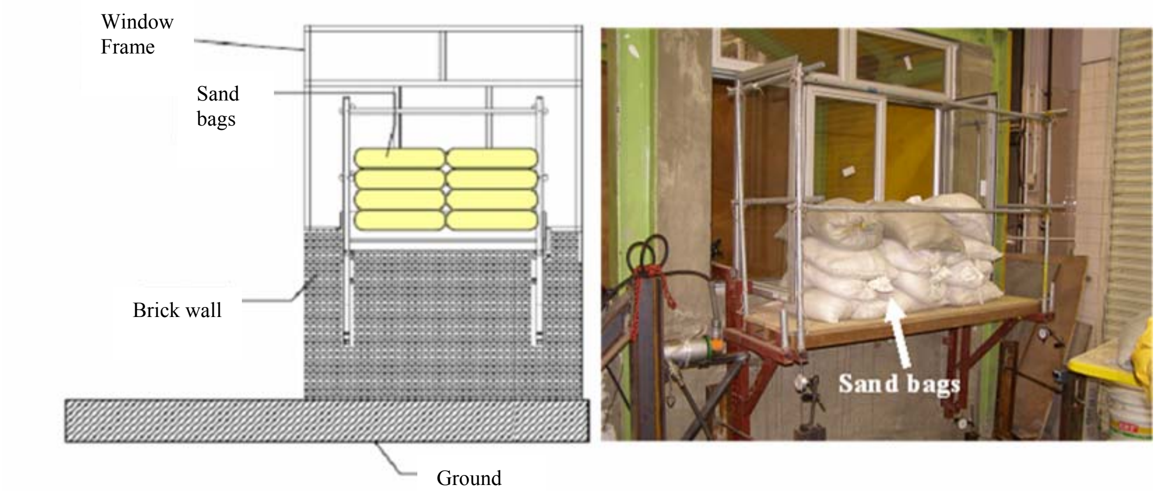
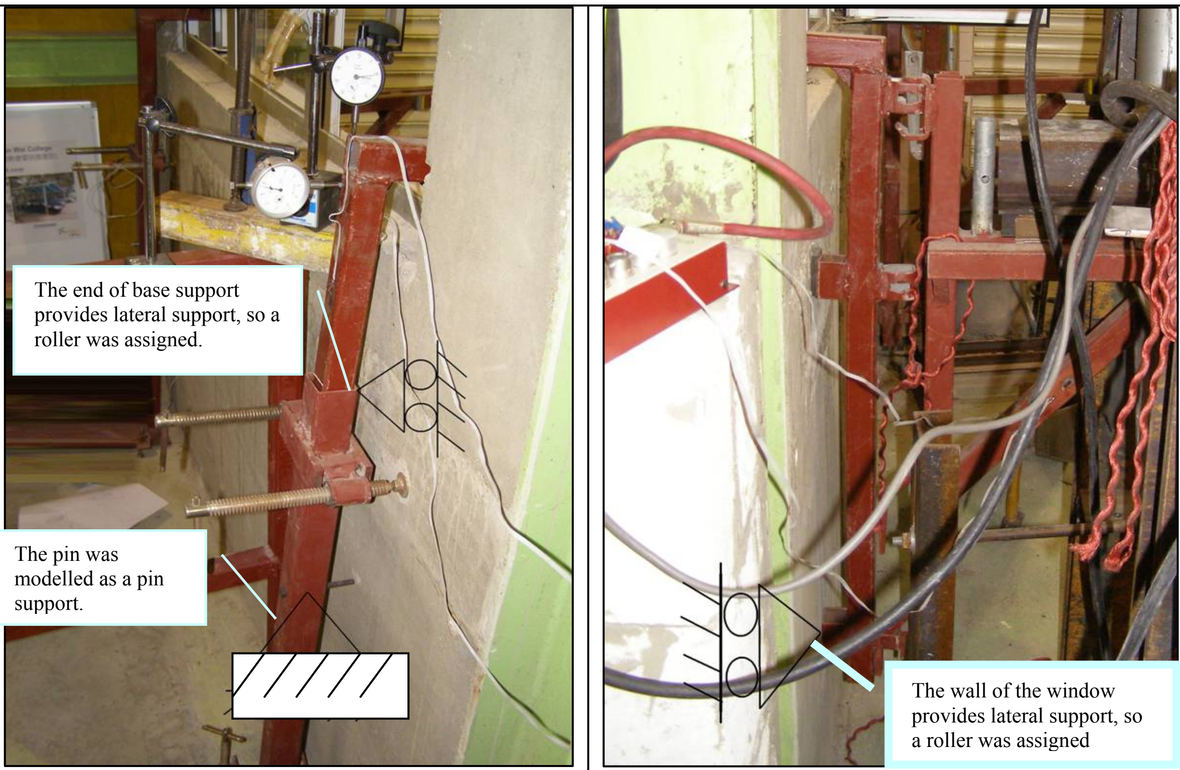


Figure 6.26: Photos of the Testing of RDP Prototype I.



(a)	(b)

Figure 6.27: RDP Prototypes Supporting Conditions.

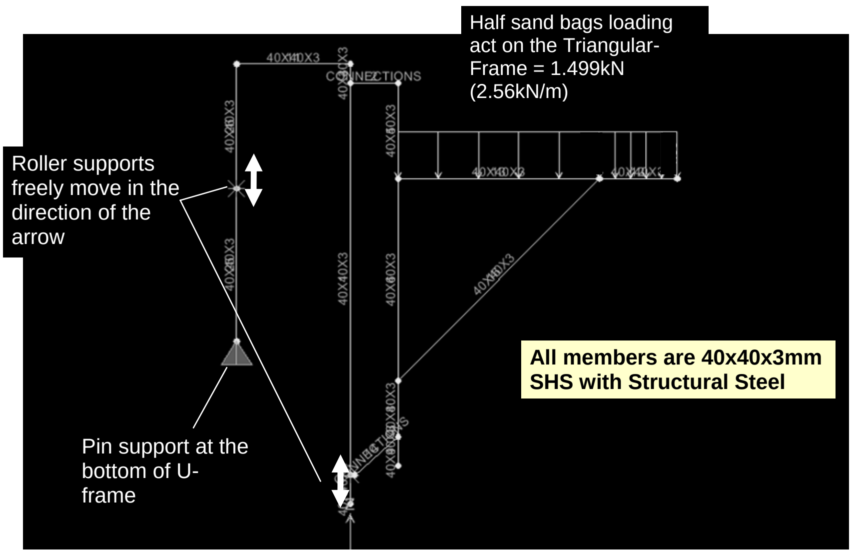


Figure 6.28: SAP2000 Numerical Model of RDP Prototype I Experimental Test.

6.6.2 Numerical Model Verification

The numerical and experimental results were compared. With the same loading condition, the maximum deflections at the tip of the triangular frame from the numerical and experimental results were 1.62 mm and 1.78 mm, respectively and similar load deflection behaviour was observed. Therefore, it is believed that the SAP2000 model of RDP Prototype I was able to predict the test result of RDP Prototype I. This model was then used as a basis to develop the numerical model for the RDP Prototype II which will be discussed in the following section.

6.7 Numerical Analysis of RDP Prototype II

The numerical models for RDP Prototype II were developed based on the validated numerical model of RDP Prototype I by changing the sections and the materials properties. The section and the material properties for RDP Prototype II are summarized in Table 6.12. The structural analysis of the RDP Prototype II was conducted using both SAP2000 and ABAQUS.

The structural analysis was carried out to predict the structural behaviour of the structural members in order to facilitate the structural design calculations. The design loading for the RDP was considered according to the codes and standards referenced. The load case of 1.4DL +1.6 IL was considered (the load case of 1.5(DL +IL) would produce a less critical condition). The wind load on the RDP was not considered since RDP is a relatively small and temporary working platform. From the Code of Practice for Bamboo Scaffolding Safety, a minimum imposed load of 2 kN concentrated load applied in a plan 300×300 mm area is the control loading for the RDP as shown in Figure 6.29. The loading areas for dead load and imposed load are shown in Figure 6.30.

6.7.1 SAP2000 Model of RDP Prototype II

A static load analysis of RDP Prototype II was carried out using SAP2000. In the model, the structural members of one side of the RDP Prototype II supporting structures, namely the U-frame and the triangular frame were modelled using the frame elements. Section sizes of the U-frame and the triangular frame were 50×30×3 mm RHS with Grade S355 steel and 25×25×2.5 mm SHS with Grade S355 steel, respectively. The elastic modulus of the structural steel is 205000 MPa (BS5950: Part 1: 2000). The support conditions are the same as those of the numerical model of RDP Prototype I, except that the base pin support is a roller support for RDP Prototype II to allow for a more conservative estimate of the member forces. Figure 6.31 shows the section properties and Figure 6.32 shows the loadings and boundary conditions of the SAP2000 numerical model of RDP Prototype II.

Table 6.12: Summary of RDP Prototype II Structural Members.

No.	Location	Material	Section
1.	U-frames	Grade S355 Steel	50×30×3 mm RHS
2.	Triangular frames	Grade S355 Steel	25×25×2.5 mm SHS
3.	Base supports	Grade S355 Steel	60×40×3 mm RHS

Code of Practice for Bamboo Scaffolding Safety

Minimum Imposed Loads			
Duty	Use of platform	Distributed load on platform	Concentrated load to be applied on plan over any square with a 300mm side and at the end portion of a cantilever
General purpose	General building work including brickwork, window and mullion fixing, rendering, plastering	2 kN/m²	2 kN

Figure 6.29: Loadings and load areas of RDP Prototype II.

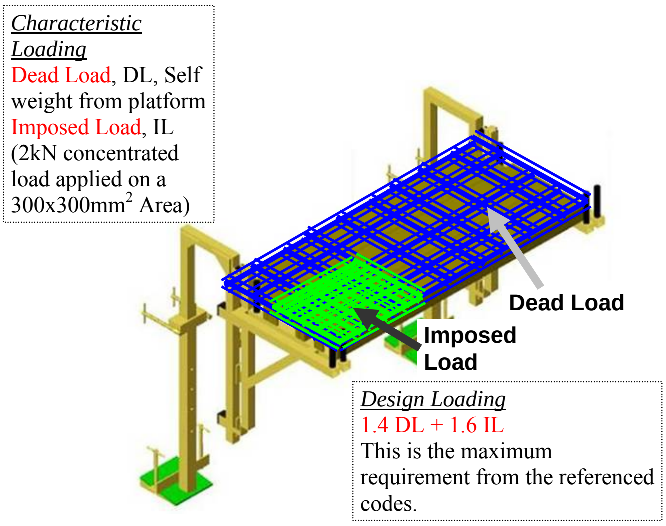


Figure 6.30: Loadings and load areas of RDP Prototype II.

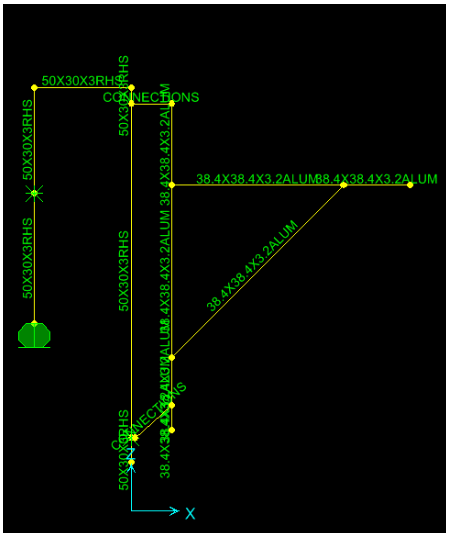


Figure 6.31: Plot of Section of SAP2000 Model of RDP Prototype II.

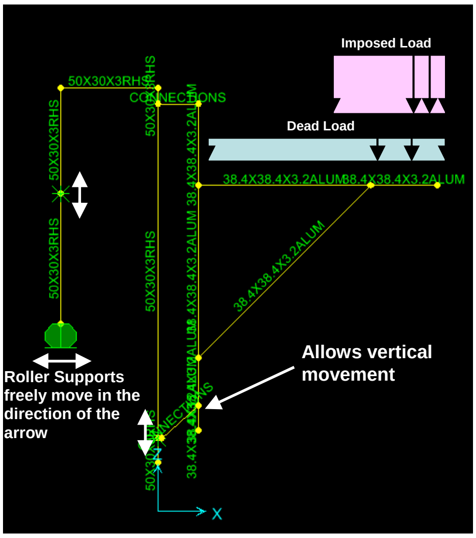


Figure 6.32: Boundary and Loading Conditions.

6.7.1.1 ABAQUS Model of RDP Prototype II

A static load analysis was also carried out using ABAQUS. ABAQUS is a powerful finite element program, which is widely adopted in the research environment. It can generate a more detailed numerical model so that stresses of the connections can be obtained. Hence, the results would facilitate the connection design. In the model, same as the SAP2000 model, structural members of one side of RDP Prototype II supporting structures, namely the U-frame and the triangular frame were modelled using brick elements as shown in Figure 6.33. Section sizes of the U-frame and the triangular frame were 50×30×3 mm RHS and 25×25×2.5 mm SHS with Grade S355 steel, respectively. The boundary and loading conditions are the same as those of the SAP2000 numerical model of RDP Prototype II.

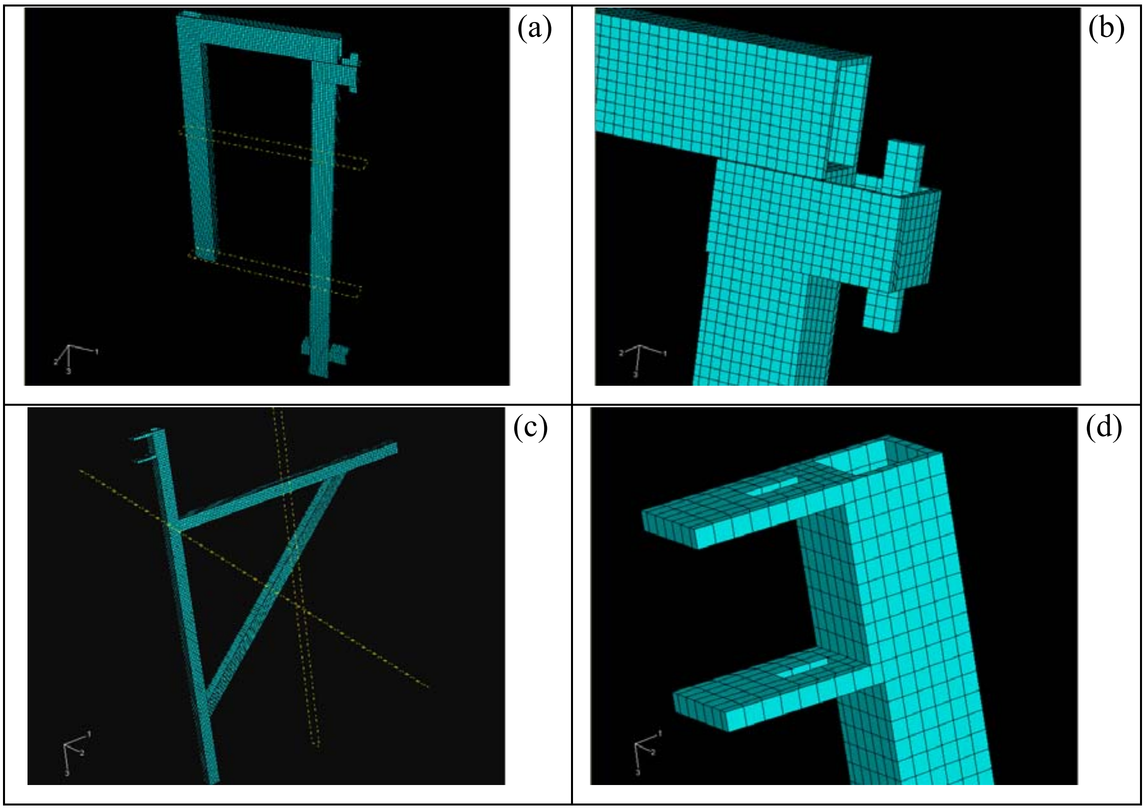
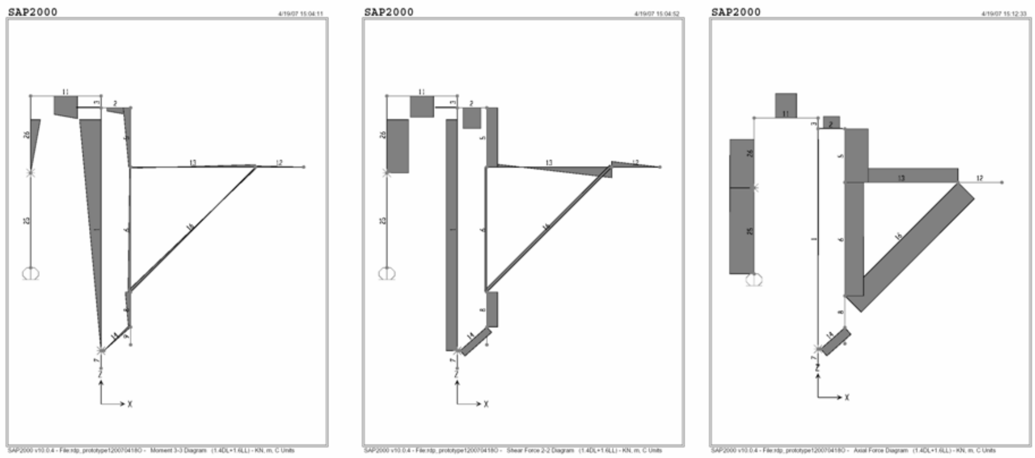


Figure 6.33: RDP Prototype II - ABAQUS Model: (a) U-frame Part; (b) U-frame Connection; (c) Triangular frame Part; (d) Triangular frame connection.

6.7.1.2 Numerical Analysis Results of RDP Prototype II

From the SAP2000 numerical model, bending moments, shear force and axial force of the members were obtained, as shown in Figure 6.34. These were used to carry out the structural design and checking the strength and adequacy of the structural members. From the ABAQUS model, stresses at various locations of the RDP are obtained, as shown in Figure 6.35. These stress values were used to check the connection design. The deformation of the ABAQUS was shown in Fig. 6.36.



(a) (b) (c)

Figure 6.34: Plots of SAP2000 Model Results: (a) Bending Moment Diagram; (b) Shear Force Diagram; (c) Axial Force Diagram.

It can be seen from Figure 6.34 that the vertical member was subjected to combined shear force, bending moment and axial force. In fact, this element was the most loaded member of the U-frame. The von Mises stress near the top connection indicated there was no yielding of the steel material as shown on Fig. 6.35. The largest von Mises stress was 299 MPa occurring at the connection near the horizontal member of the U-frame. The overall deformed shape of RDP Prototype II indicated that there was bending deformation of both the U-frame and the triangular frame which caused the structure to rotate as shown in Figure 6.36

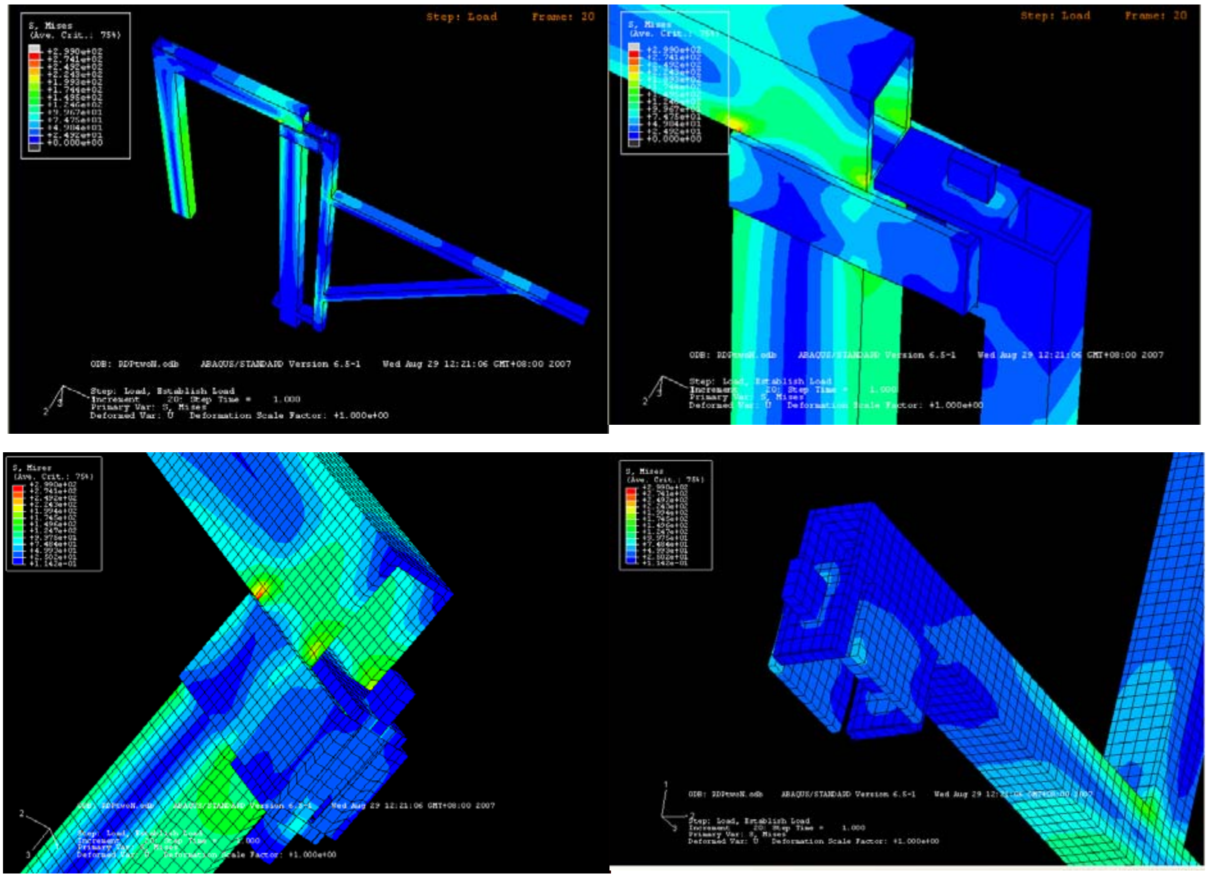


Figure 6.35: Typical Plot of Stresses of ABAQUS Model.

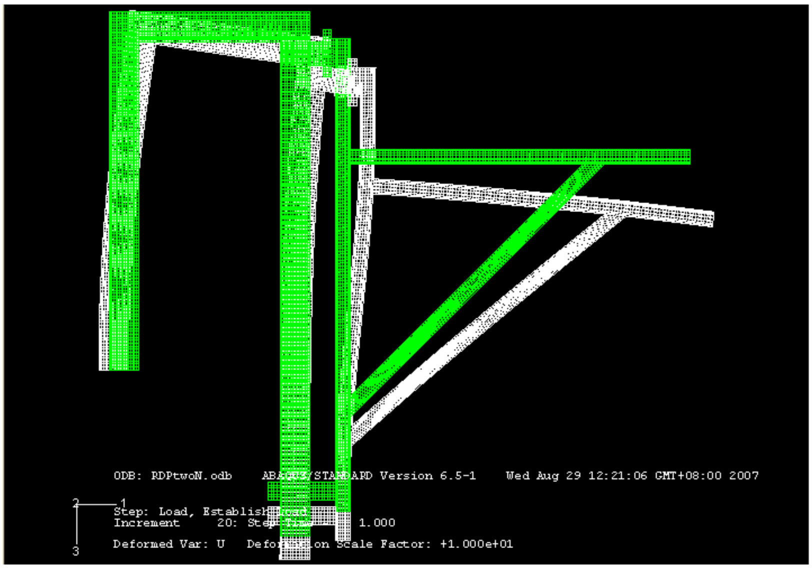


Figure 6.36: Typical Plot of Deformation of ABAQUS Model.

6.8 Structural Design Calculations Example of RDP Prototype II

The structural design followed the Code of Practice for the Structural Use of Steel 2005, Buildings Department. A design example is shown in Figures 6.36 to 6.37

As can be seen from the calculation, the members were designed as a beam-column which resisted both axial load and bending moment. The example shows that the U-frame (critical member) is structurally adequate for the applied loading. The design calculations for the all other structural elements are listed in Appendix 8.

The ABAQUS results indicated that the maximum von Mises stress existed in the RDP Prototype II was 299 MPa which was lower than the design strength of Grade S355 steel of 355 MPa. Therefore, it can be seen that the RDP Prototype II will behave elastically under the factored load condition and hence, the design is satisfactorily.

The Hong Kong Polytechnic University			
Project : Developing a Prototype for a Rapid Demountable Platform (RDP)			
Calculation for/Subject:	Structural Calculation for RDP Prototype II		
Prepared by: Tracy Chung	Checked by: M.Y.	Date: 26/9/2007	

Ref.	Details	Output/Action
	Design Calculations Example:	
	Member checking of 50x30x3mm RHS	
	Properties:	
	Area (mm^2) = 440 d/t = 13.7	
	I_{xx} (mm^4) = 139000 b/t = 7	
	Z_{xx} (mm^3) = 5540 80ε - d/t = 56.71	
	S_{xx} (mm^3) = 7010	
	r_{yy} (mm) = 11.7	
	Classification of cross sections:	
Ref. 1 Table 7.2	Limiting width-to-thickness ratios for CHS and RHS. For Compression Element Flange: Compression due to bending b/t limiting value = 28ε = 24.6 where $\varepsilon = \sqrt{(275/355)}$ = 0.8801	
	b/t = 7 < 28ε ==> Class 1 ==> Plastic Section	
	Web: Neutral axis at mid-depth d/t limiting value = 64ε = 56.3 where $\varepsilon = \sqrt{(275/355)}$ = 0.8801	
	d/t = 13.7 < 64ε = 56.3 $\leq 80\varepsilon$ -d/t = 56.71 ==> Class 1 ==> Plastic Section	
	$r_1 = F_c / (2\ d\ t\ p_{yw})$ $64\varepsilon/(1+0.6r_1)$ but $\geqq 40\varepsilon$ = (40)(0.8801) = 35 d/t = 13.7	==> OK
Ref.1 Clause 8.3.5.1 Table 8.2	**If SHS or Limiting value of L_E/r_y for RHS less than the value shown in Table 8.2, the section need not be checked in lateral-torsional buckling.** **Ratio** **D/B =** 50/30 = 1.67 Limit Value = $435\varepsilon^2$ **==> No need check for lateral torsional buckling**	

Page 22of 26

Figure 6.37: Design calculation example of Steel member (Page 1).

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by: M.Y.	Date: 26/9/2007

Ref.	Details	Output/Action
	Cross-Section Capacity:	
Ref. 1 Clause 8.9.1	**8.9.1 Cross-section capacity** Except for Class 4 slender cross-sections, the cross-section capacity can be checked as, $\frac{F_c}{A_g p_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}} \le 1$ (8.78) in which M_x and M_y are the design moments about the x- and y-axes. M_{cx} and M_{cy} are the moment capacities about the x- and y-axes.	
	Element 11 **Case:** P-delta effect **Section Size:** **50x30x3mm RHS** **From SAP2000 Analysis Output as shown in Page 19** Axial Force, F_c = 4.177 kN Shear Force, V= 3.175 kN Major Moment, M_x = 1.6117 kNm Minor Moment, M_y = 0 kNm	
	Properties of 50x30x3mm RHS : Area (mm^2) = 440 d/t = 13.7 I_{xx} (mm^4) = 139000 b/t = 7 Z_{xx} (mm^3) = 5540 80 ε - d/t = 56.71 S_{xx} (mm^3) = 7010 py = 355 MPa r_{xx} (mm) = 11.7	
	$F_c/ (A_g\ p_c)$ = 0.0444 M_x/ M_{cx}= 0.6829 M_y/ M_{cy}= 0	
Ref. 1 Clause 8.9.1 Eq. 8.78	Mc = Min(PyS, 1.2PyZxx) = 2.36 kNm $\frac{F_c}{A_g p_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}}$ = 0.73 ≤ 1	==> OK

Figure 6.38: Design calculation example of Steel Member (Page 2).

The Hong Kong Polytechnic University		
Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung	Checked by: M.Y.	Date: 26/9/2007

Ref.	Details	Output/Action

Non-sway

$$\frac{F_c}{P_c} + \frac{m_x M_x}{M_{cx}} + \frac{m_y M_y}{M_{cy}} \leq 1$$ Where M_y = 0.00

$$\frac{F_c}{P_{cy}} + \frac{m_{LT} M_{LT}}{M_x} + \frac{m_y \overline{M_y}}{M_{cy}} \leq 1$$

Assume m_x & m_{LT} = 1.0 (Conservative).

$M_x = M_{cx}$ ==> No need to check Lateral Torsional Buckling for the RHS members

∴ Evaluate P_{cy} & assume an effective length

L_E = 1000mm K = 1.0

∴ r_y = 11.7 mm

∴ L_E/r_y = 85.5

∴ p_c = 214 MPa

$$\frac{4.177}{(214)(440)(10^{-3})} + \frac{(1.0)(1.612)}{(355)(5540)(10^{-6})} = 0.864 \leq 1$$

Bolted Connection - The pin location to support the U-Frame

M10 Bolts = Grade 8.8

p_s = 375 MPa

p_{bb} = 1000 MPa Double shear

p_{bs} = 550 MPa threads not in shear plane

Bolt Shear = $\pi \times 5^2 \times 375 \times 2 \times 10^{-3}$ = 59 kN

Bolt Bearing = $3 \times 10 \times 1000 \times 2 \times 10^{-3}$ = 60 kN

Plate Bearing = $3 \times 10 \times 550 \times 2 \times 10^{-3}$ = 33 kN ==> OK

Welding

All welds are 5mm weld all around - no need to check matching electrode (Grade 42)

Figure 6.39: Design calculation example of Steel Member (Page 3).

6.9 Summary

In order to ensure the reliability of the RDP Prototype II, the structural adequacy of RDP Prototype II was checked against the requirements of the prevailing regulations and code of practices in Hong Kong. RDP Prototype I was tested experimentally. The experimental results were used to verify the corresponding numerical model. Subsequent to the validation of the numerical model, the RDP Prototype I numerical model was modified to RDP Prototype II numerical model, by changing the section and material properties. With the RDP Prototype II numerical model, member forces and deformation could be predicted. Hence, the RDP Prototype II was designed. The RDP Prototype II was fabricated and tested experimentally. The test results showed that the RDP Prototype II is structural adequate according to the "General purpose duty" category of the Code of Practice for Bamboo Scaffolding System. Detailed design checks were conducted to verify the design of the RDP Prototype II.

Chapter 7 — Conclusion and Recommendations

7.1 Introduction

With reference to the previous Stage I project on “Construction Safety Involving Working at Height for Residential Building Repair and Maintenance”, the high accident rate on fall resulted from residential building repair and maintenance works has urged for an imperative solution. In this connection, an alternative temporary working device, the RDP, was thereby conceived. The initial design of RDP has brought to the current project for fine-tuning in the aspects of user-friendliness and safeness.

7.2 Review of Project Objectives

The aim of this project was to refine the RDP Prototype I based on sound engineering design, user friendliness concept and aesthetics. The process of refinement has undergone several stages. The generation of idea was firstly inspired through comments from practitioners, task force members and in-house team members. Consolidated suggestions were deliberated by the research team. Liaison between designers and engineers within the research team went on whenever technical difficulties encountered. Finally, the feasibility of usage in actual environment was examined under relevant testing. The objectives of this study are:

- To refine the RDP Prototype I
- To develop RDP Prototype II using alternative materials to Prototype I
- To analyze whether the prototypes are durable and safe to be used for external building inspection, repair and maintenance works.
- To investigate the acceptability and practicability of the prototypes by various parties.
- To suggest the most suitable design for the final prototype.

7.3 Achievement of Objectives

The listed objectives have been accomplished and are summarized below:

Objective 1 - To refine the RDP Prototype I.

RDP Prototype II was refined from the Prototype I. In order to enrich the idea generation, diverse activities were arranged. As a start, the research team was strengthened by the input of production design expertise. Organizing workshops could gather ideas from industrial practitioners according to their expertise. Also, the site visit to the machinery workshop of SHKP broadened the availability of technical skills. All these works were of significance to the refinement of RDP Prototype II. Table 7.1 summarized the past actions arising from the refinement of RDP Prototype I:

Table 7.1: Actions Taken for the Refinement of RDP Prototype I.

Project team	• Input of design expertise
Workshops	• Industrial practitioners
	• Front-line workers with working at height experience
Site visit	• Machinery workshop of Sun Hung Kai Properties (SHKP)

Objective 2 - To develop RDP Prototype II using alternative materials to Prototype I.

The use of alternative materials was a breakthrough in the RDP Prototype II. Wooden planks and toe-boards were replaced by lighter aluminum sheets. This change could exclude the wear and tear problem caused by wood. In addition, five sets of aluminum railing panels have substituted the discrete galvanized iron pipes in RDP Prototype I. The applied modular concept on the railing-panel design could further speed up the installation time. Although the triangular frames have once considered to be replaced by aluminum section, possible risks as a result of lower stiffness of aluminum and the lack of welding control might be incurred. The computer simulation has placed an important role to this issue. Steel was subsequently retained as the materials for the triangular frames while a thinner and lighter steel section with higher grade (Grade S355) was adopted (See Table 7.2). Computer simulation verified that the capacity of the thinner steel section was sufficient to resist the required loadings.

Objective 3 - To analyze whether the prototypes are durable and safe to be used for external building inspection, repair and maintenance works.

Objective 3 was achieved through the structural testing and modeling techniques. Typical loading tests were conducted in both prototypes. Experimental results indicated the strength of the RDP is up to the Hong Kong codes and standards. Testing on RDP Prototype I has gathered useful information for the development of RDP Prototype II. With the input of design concepts and refinements, computer simulation could assist to conduct a parametric study for the RDP. The RDP Prototype II has been derived based on the model analysis. Further experimental testing on RDP Prototype II has confirmed the strength and rigidity of its structural elements.

Objective 4 - To investigate the acceptability and practicability of the prototypes by various parties.

Objective 4 was fulfilled via the invitation of practitioners to workshop and interviews. To collect comments on RDP Prototype I, one demonstration session and one focus group workshop were organized. Most of them appraised the RDP positively and yet the device was a bit raw to launch. Ideas on materials, weight, the applicability and the strength of external parapet walls were captured through survey questionnaire and group discussions. Practical comments were obtained and incorporated to the design of RDP Prototype II.

Besides, seeking advice on the proposed market launch of RDP was carried out via face-to-face interviews. The interviews with OSHC and BD have provided valuable suggestions and necessary considerations to this issue.

Objective 5 - To suggest the most suitable design for the final prototype.

The RDP Prototype II was refined based on the skeletons of RDP Prototypes I. Nevertheless, most of the deficiencies of RDP Prototype I have been eliminated and several new design concepts have been incorporated in the RDP Prototype II. The mockups both prototypes were delineated in Figure 7.1 while the major changes were outlined in Section 7.4.

Figure 7.1: The Mockups of RDP Prototypes I and II.

7.4 Comparison of RDP Prototypes I and II

A comprehensive comparison between RDP Prototypes I and II was made in Table 7.2. The table highlighted the RDP modifications under the headings of fabrication materials, design concepts, installation time and self-weight.

Table 7.2: Comparison between RDP Prototypes I and II.

		Prototype I	**Prototype II**
Materials	**Standing panels**	• Hardwood	• Aluminum panels with sinkholes
	U-frame and triangular frame	• Steel SHS in 40×40×3mm • Grade 43	• U-Frame: 50×30×3mm steel RHS • Triangular frame: 25×25×2.5mm steel SHS • Grade S355
	Railing panels	• Galvanized iron pipes	• Aluminum pipes
	Toe-boards	• Hardwood	• Aluminum sheets
Design	**Modular concept**	• Local design	• Standing panels and railing panels in unit dimensions
	Product semantics	• Local design	• Toe-boards and base support in zebra stripes
	Standing boards	• 3 rectangular planks in longitudinal direction	• 3 square sheets in transverse direction
	Interlocking system	• Fixing by pins	• A pair of C-ring with screw attached
Installation time		• 15 min	• 10 min (33% less)
Weight		• 95 kg	• 81 kg (15% less)

7.5 Recommendations for Further Improvement

This section presents some key recommendations as a result of the findings from this project.

7.5.1 General Recommendations

1. Search for efficient solution to determine the suitability of wall for the use of RDP should be conducted.
2. A detail examination on the application procedure for certification or recognition should be carried out. For example, inputs from LD could provide instructions or necessary information for the commissioning process.
3. The packaging design should be further considered for the transportation of RDP to the work site.

7.5.2 Technological Recommendations

Several technological recommendations were suggested for further improvement:

1. Platform panels could be coated with plastic material to avoid slippage and electrical insulation.
2. The pins for fixing could be more rigid.
3. A leveling bubble could be attached to the base support or the railing panel of RDP to ensure the installation is level.
4. The RDP may consider accommodating the replacement of U-shape trap of the drainage pipes where was believed to be the possible spreading source of Severe Acute Respiratory Syndrome (SARS).

7.6 Benefits of the Research

This study mainly focused on the production of the RDP Prototype II as an alternative platform to reduce fall accidents involved in working at height. A comprehensive investigation has been carried out before the production of RDP Prototype II. While the RDP Prototype I was made from readily available materials in the laboratory, engineering design and industrial comments were included in the development of RDP Prototype II. Moreover, the strength and safety of RDP Prototype II was verified by a series of structural testing.

The RDP is a brand-new device which is particularly suitable for small-scale external maintenance works involving working at height. It does not cause damages on the external wall; and furthermore, this device could eliminate the necessity to hire a separate trade to erect the truss-out scaffold which is always costly to small projects.

7.7 Limitations of the Study

The limitations of this study are listed below:

1. The survey on RDP Prototype I was only responded by 9 people. The response rate was not high enough to reflect the overall view from the industry. A higher response rate could generate a more representative analysis.
2. The duration of study was limited to carry out another round of demonstration and workshops on the RDP Prototype II.
3. Time was insufficient to solicit comments from the bamboo truss-out scaffold industry. Their inputs could provide insightful suggestions on the refinement of RDP Prototype II.
4. Although significant effort has been put in the re-engineer the design of the RDP Prototype II, more efforts should be put to refine the connection details and to further improve the rigidity of the entire system.

7.8 Recommendations for Future Research

The following suggestions are valuable for future research:

1. Inviting practitioners’ comments on the RDP Prototype II.
2. Further study on the structural design of the prototype.
3. Designing a package for storage and transportation.

4. Investigating the feasibility of further weight reduction.
5. Finalizing the market launching procedures.

7.9 Summary

The current practice for doing external maintenance work in Hong Kong is to erect a temporary platform by way of a bamboo truss-out scaffold supported by steel brackets. However, the practice appears to be highly unreliable and a number of fatal accidents have occurred. Problems identified in this system include lack of standardized brackets, unpredictable wall conditions, improper installation, low quality anchor bolts, lack of personal protective equipment etc. Despite these limitations, the prevailing form of bamboo truss-out scaffold has its value to the construction industry. However, every effort should be placed to overcome these limitations. The development of RDP is one such attempt to provide a safe, rapid, user-friendly demountable temporary working platform for inspection, repair and maintenance works on external wall of buildings. The newly system is particularly suitable for small-scale maintenance works such as external building inspection, change of air-conditioning unit, maintenance on plumbing/drainage system, painting, plastering and tiling/rendering. Alternatively, the RDP can be used as a temporary stepping device for the erection of traditional bamboo truss-out scaffold, but in a much safer, more reliable and user-friendly working condition. The launching of RDP is expected to significantly enhance the safety for doing external maintenance works. However, the RDP is still at its prototyping and germinating stage, comments and suggestions from practitioners and end-users are essential for its further refinement and improvement.

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Appendix 1 – Sample of Questionnaire on RDP Prototype I

Rapid Demountable Platform (RDP) Demonstration on 4th Sept 2006
Feedback Questionnaire

Aim: The following questions are based on the RDP demonstration held on 4th Sept 2006. The aim of this questionnaire is to obtain professional advice from experts who attended the demonstration. And therefore refine the design of the RDP to be safer and more practical for use in external repair and maintenance works for residential buildings.

Instruction: The questionnaire will take approximately 2 minutes to complete. Please kindly tick the appropriate box for your answer.

Respondent's Information

1. Name of your company/organization: ____________________________________
2. Job nature/working position: ____
3. Years of experience in construction safety: ________________________________
4. Years of experience in construction safety for repair and maintenance works: ______

Comments on the RDP Demonstration

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
5. The RDP is safe to use for external repair and maintenance works.	❑	❑	❑	❑	❑
6. The speed of installation/dismantle is appropriate in a real life situation.	❑	❑	❑	❑	❑
7. The RDP is simple to use for workers.	❑	❑	❑	❑	❑
8. The RDP could replace the bamboo truss-out scaffold.	❑	❑	❑	❑	❑
9. The design of the RDP does not need improvement.	❑	❑	❑	❑	❑
10. The RDP is too heavy.	❑	❑	❑	❑	❑
11. I would encourage my staff/colleagues to use the RDP.	❑	❑	❑	❑	❑
12. The RDP should have fewer components.	❑	❑	❑	❑	❑
13. The RDP appears to be durable.	❑	❑	❑	❑	❑
14. The RDP is useful for the majority of old residential buildings in Hong Kong.	❑	❑	❑	❑	❑
15. The RDP should be designed using other materials such as aluminum.	❑	❑	❑	❑	❑

16. Do you have any further suggestions towards improving the RDP design?

____

____

Appendix 2 – Notes of Focus Group Workshop with Front-line Workers (Chinese version only)

快速安裝平台研究及應用
座談會會議記錄
2007 年 3 月 29 日(星期四)

地點: 香港理工大學 Y 棟 4 樓 407 室
時間: 晚上 8 時至 9 時 30 分
主辦單位: 香港建造業研究學會
香港理工大學建築及房地產學系
香港建造業總工會
香港建築業承建商聯會香港建造業總工會

香港建造業總工會: 嚴鋼盛 先生
香港建築業承建商聯會香港建造業總工會: 費榮富 先生 、 潘家強 先生
陳國和 先生 、 何慶新 先生

香港理工大學建築及房地產學系: 陳炳泉 教授 、 黃君華 教授
任志浩 博士 、 陳煒明 博士
林偉明 博士 、 盧智恆 先生
張泳沁 小姐 、 蔡詠琪 小姐

I. 參加者資料

報名人數: 35 人
出席人數: 21 人 (名單見下表)

	參加者		參加者
1	費榮富	16	溫俊建
2	潘家強	17	劉桂全
3	陳詠麟	18	林慶安
4	何煜常	19	陳國和
5	何一鳴	20	何慶新
6	徐志良	21	李偉忠
7	梁祥		
8	費榮和		
9	何詠詩		
10	梁晶瑩		
11	嚴鋼盛		
12	譚偉雄		
13	鄺國梓		
14	李光昇		
15	李龍生		

參加者已預先分爲四組, 並分派理大職員加入各組討論。
藍組: 任志浩博士
紅組: 林偉明博士
綠組: 張泳沁小姐
黃組: 蔡詠琪小姐

II. 程序

20:00　報到及登記
20:10　歡迎及開幕詞 (司儀: 陳煒明博士, 開幕詞: 黃君華教授)
20:15　放映快速工作平台安裝及拆卸影片
20:30　討論有關快速安裝平台之意見
21:00　分組報告
21:25　結束詞 (陳炳泉教授)

III. 問題討論及回應 (*斜體字型爲參加者之回應*):

1. 「快速安裝平台」是否能安全地應用於大厦外牆之維修及保養工作嗎? 有潛在的危險嗎?

   - *如應用於舊式建築物上, 外牆牆身可能不夠堅固承受快速安裝平台的重量而導致危險。考慮到新的建築物外牆一般較堅固, 此平台應較合適及安全應用於此類建築物上。*

2. 與傳統「 外伸桁架式竹棚架」相比,「快速安裝平台」的安裝及拆卸速度是否較優勝?

   - *對於小型外牆維修, 快速安裝平台比傳統棚架較方便及優勝 。*

3. 就工人而言,「快速安裝平台」是否容易安裝及使用?

   - *安裝過程容易掌握, 建議可安排工人使用此工作台前參加半天的安裝課程; 只要附有安裝工序作參考, 就應該不構成問題。*

4. 你認爲「快速安裝平台」能否取代現存的傳統外伸竹棚架嗎? 請說出原因。

   - *快速安裝平台並不能取代傳統的棚架, 此工作台的應用受到環境限制, 局限於某類型的樓宇及位置。對於現時比較熱門的窗框更換工程項目, 由於窗框會被 u 型架卡著, 此工作台便不能應用; 一般冷氣及玻璃更換工程則比較合適, 亦可以降低此類維修工程因而導致竹棚安裝及拆卸之成本。*

5. 「快速安裝平台」是否有改善的空間嗎? (可於設計及用料方面討論)

   a) 設計方面：
   - *工人於此工作台上的可活動範圍受到限制, 工程如修補水管滲水一般處於窗框較低位置, 遇到同類型工作, 此平台難免有限制, 欠缺靈活性。*
   - *另外, 工作台的長度不能改變, 用途會受到窗的尺寸受到限制。建議可配有不同闊度, 增加使用之彈性。*
   - *現正使用木板作爲企板, 在高空工作時會受到風力影響而不方便安裝; 及此類木板會隨著天氣變化而導致拆斷。*

   b) 用料方面：
   - *顧及安全及耐用起見, 企板建議可考慮使用較輕之金屬代替木板, 如鋁合金或鋅鐵板。*
   - *企板可改用疏孔板, 有利於去水。*

c) 安裝方面 :

- *室內螺絲觸及之牆身可考慮加上膠墊, 以防止牆身被刮花。*
- *確保欄杆固定, 不會因爲受力而移動。*
- *改善鉸位的接駁裝置, 考慮採用有保險掣鎖定接駁處。*

6. 「快速安裝平台」的組合配件過多嗎?

- *可考慮減省室內支架。另外, 工作台本身重量太大, 顧及高空工作一般只有兩個工人, 要他們在開始工作前先要搬運這個二百鎊的負擔, 有點吃力。*

7. 「快速安裝平台」的耐用性高嗎?

- *木板有拆斷的可能性, 不建議使用 (參考 Q.5a 意見)。*

8. 「快速安裝平台」能否適用於香港的舊式住宅樓宇之維修及保養工作嗎? 請舉例說明。

- *對於現存的樓宇, 此工作台的應用較爲局限, 窗門尺寸及可活動範圍最直接影響此工作台的普及程度。*

9. 如果「快速安裝平台」推出於市場, 你是否會購買?

- *如經安全測試合格, 一般都會考慮使用。 建議最好有租用服務, 除了可進一步減省成本外, 亦不用額外儲存空間。*

10. 有甚麼途徑能使工友們懂得如何有效率地使用「快速安裝平台」?

- *由於時間不足, 未能作出回應。 有關內容可參考 Q.3 的意見。*

Appendix 3 - Notes of Meeting with OSHC

Research Topic:	Developing a Prototype for a Rapid Demountable Platform (RDP)
Members Present:	*Occupational Safety and Health Council (OSHC):* [redacted] (Executive Director) [redacted] (Senior Consultant) [redacted] (Publicity Officer) *The Hong Kong Polytechnic University (PolyU):* Daniel CHAN (Assistant Professor) Esther CHEUNG (Research Associate)
Interview Date:	7th August 07 (Tuesday)
Interview Time:	15:30 – 16:35
Interview Venue:	Occupational Safety and Health Council, Meeting Room, 19/F, China United Centre, 28 Marble Road, North Point, Hong Kong

A 'Flow Chart Showing the Market Launch of the Rapid Demountable Platform (RDP) in Building, Construction, Repair and Maintenance Sector' was sent to Mr. [redacted] prior to the meeting. The purpose of this meeting was to collect Mr. [redacted]'s comments and suggestions based on the flowchart. The following notes were taken in the meeting:

<u>Mr. [redacted]</u> informed that each product must seek Labour Department's approval before they will consider subsidizing it. Also there is no more funding for this year. He also pointed out that the RDP would need inspections similarly to tower platforms. Therefore the cost for inspection also needs to be considered. Mr. [redacted] questioned whether the research team had spoken to Labour Department.

<u>Daniel</u> replied that the research team tried to speak to Mr. [redacted] of Labour Department but he has recently retired.

<u>Mr. [redacted]</u> informed Daniel that there was no use speaking to them at this moment. Instead the research team should take the RDP to Labour Department and demonstrate to them to seek their approval. Mr. [redacted] raised that if they funded the RDP, people would question why they haven't also funded normal scaffolding. He explained that further testing on the product would be useless, instead the research team needs to seek Labour Department's approval first. A main problem with the RDP is that there are no standards which can be followed unlike the TTAD.

<u>Daniel</u> explained that the RDP does not aim to replace truss-out scaffolds completely but instead used as an alternative or a supplement.

<u>Mr</u>[redacted] felt that it might be more convenient to use the truss-out scaffold alone.

<u>Daniel</u> pointed out that the truss-out scaffold possesses safety issues during installation and dismantling. Also there are problems with drilling holes for the anchor bolts.

Mr. [redacted] pointed out that there are instruments available on the market that can drill holes at an angle. But there is the main problem of whether workers will use these instruments. Again Mr. [redacted] emphasized the importance of Labour Department's approval especially in writing. Also, he pointed out that the research team should consider opposition from scaffolders. Political consideration is important even if the product is good. He believes that training is not a problem they would be willing to coordinate with the other things as long as there is approval. Mr. [redacted] raised that they are not distributors, they just subsidize. He further queried the size of the RDP.

Daniel replied that the RDP is 1350 mm in length and can be adjusted to two height levels. In addition the time to install the system takes approximately 10 minutes only.

Mr. [redacted] believed that the time of installation is not the main consideration. He believed that people could use tubular scaffolding to reinvent their own RDP. Again he emphasized the necessity to have the RDP approved before needing to consider the issue of certified workers and competent persons. Mr. [redacted] questioned who the manufacturer would be.

Daniel replied that manufacturing wasn't the top priority of the research team at this stage.

Mr. [redacted] asked the price for the research team to produce the RDP.

Daniel estimated that the cost was approximately $3000.

Mr. [redacted] further asked the cost of the RDP if launched to the market.

Daniel estimated that it would be $5000.

Mr. [redacted] pointed out that the RDP was limited to certain buildings only.

Daniel believed that approximately 30% of buildings in Hong Kong could use the RDP.

Mr. [redacted] responded that they would need to consider whether to subsidize this product as it would only cover 30% of buildings. In addition, the cost of the product is quite high so other options could be considered instead. Mr. [redacted] believed that there must also be profit margins for the supplier. Also, if there was a specified manufacturer he worried about the lack of competition.

Mr. [redacted] pointed out that the main problem was that there were no international standards governing the safety of the product. For example, ladders purchased abroad can be checked by international standards.

Mr. [redacted] informed that they had introduced the T-frame bracket to ease the process of fixing the anchor bolts, but workers still have excuses not to use them. The workers claim that the T-frame is heavier and more difficult to transport due to its shape. But in actual fact workers prefer to take risks rather than to change their normal practice. Mr. [redacted] believed that the workers may feel it to be a hassle to construct a RDP for a truss-out scaffold as the procedure is repetitive.

Daniel believed that the truss-out scaffold is dangerous to construct.

Mr. [redacted] saw the same risks for the RDP. Again he indicated that the top priority was to seek Labour Department's approval in writing by demonstrating the system to them. In addition, if the RDP needs to be inspected, there needs to be the consideration of who pays for it. Mr. [redacted] indicated their difficulties to subsidize a product if it is limited to licensed distributors only.

Daniel explained that the RDP was designed to prevent fall from height accidents.

Mr. [redacted] explained that their members would be concerned of the responsibility issue if an accident did occur. For the TTAD the BS standard could be referred to. For the T-frame the Buildings Department code of practice could be referred to. So for each of these cases the responsibility would be another party's. Also, he believed that there is no way to prevent someone from reinventing the concept using different sizes and materials.

Daniel said that the research team would also visit other departments. Buildings Department would be visited on Friday.

Mr. [redacted] suggested that the research team should persuade Labour Department to include the system in their code of practice. Again he urged the necessity to get the departments involved aboard.

Daniel agreed that the research team would seek advice from these departments. He informed that the current research project will be finished at the end of next month and the actual launch of the system will be considered at a later stage.

Mr. [redacted] explained that they will consider subsidizing the system after the departments have approved it and the system has been commercialized. He reminded that they would not act as a distributor as they do not wish to take on the responsibility. Also, he knows that departments will only endorse a practice and not a specific product design.

Mr. [redacted] added that they have no rights to endorse these designs anyway. But what they can do is not oppose.

Mr. [redacted] also added that this was the situation with aluminum scaffolding.

Daniel explained that licensed suppliers were considered to prevent other unsafe versions of the RDP available on the market.

Mr. [redacted] still raised his concern on the lack of competition problem that this would bring.

Daniel questioned whether the TTAD can be purchased from many suppliers.

Mr. [redacted] answered that this was correct as it is a free market, so they believe that as long as it is compatible with BS standards it would be suitable. As a result he suggests we use the term 'supplier' rather than 'licensed supplier', as it is better for competition to be increased and as a result the system can be cheaper. Also, he suggested that the research team should ask Labour Department concerning the issue of maintenance and inspection, as if this is required by them the cost will be increased.

Mr. [redacted] added that insurance costs must also be considered.

Mr. [redacted] agreed. He suggested the research team should consider why the Labour Department would exempt the RDP from inspection and not other scaffolding systems. In addition a specific RDP course would be too narrow and the workers would find it a hassle. Instead he suggested that the RDP utilization could be included in other general or scaffolding courses.

Mr. [redacted] raised that bamboo scaffolding has its advantages as old bamboo can be replaced easily by new bamboo.

Mr. [redacted] pointed out that the flowchart does not include inspection by Labour Department. But according to laws for the truss-out scaffold this system should also be obliged to their inspection.

Mr. [redacted] added that even if the RDP is moved from one window to one next to it, by law examination is required.

Mr. [redacted] informed that if Labour Department approves the system, they will also approve it as they will not need to take the responsibility. He raised that tubular scaffolding in the U.K. is constructed similarly to the RDP. And even if Buildings Department approves the system, the Labour Department may still not. Mr. [redacted] pointed out that the biggest problem of the system is that there are no standards which can be referred to. He also pointed out that CITA's vertical pole faces similar problems as the RDP. Also, Labour Department has recently sued a RPE for not actually inspecting works that he has approved. Labour Department is now a lot stricter he added.

Daniel expressed that it is hoped the RDP will belong under one of the minor works groups.

Mr. [redacted] was not hopeful that the bill would be in the near future. He still believed that Labour Department's approval first is the priority. And also the RDP should be taught in for example one of CITA courses instead of separately. If a specific course is designed there may be unwanted opposition. Mr. [redacted] repeated that after seeking Labour Department's approval the research team could explore whether examination each time would be required. He suggested the research team study the COP well.

Daniel raised that the RDP's advantage was that it is non-destructive to walls.

Mr. [redacted] answered that a fixed anchor point could be adopted as TTAD is just a temporary solution.

Daniel asked who should be approached at Labour Department as Mr. [redacted] has retired.

Mr. [redacted] suggested the new colleague in Mr. [redacted]'s position.

Daniel added that focus groups will be held to gather views from workers.

Mr. [redacted] worried that the workers invited to the focus group would not be the people that are involved with these works. Also, he explained that subsidizing schemes are only temporary as the responsibility should be the workers'.

Daniel questioned how long the TTAD subsidizing scheme would go on for.

Mr. [redacted] answered that the subsidizing schemes would not be stopped but a lack of demand can be observed. So they would also change depending on the market demand.

Mr. [redacted] added that the workers who will use TTADs have all participated in the scheme already.

Mr. [redacted] has observed that estate management companies have either enforced their contractors to purchase the TTAD or they have purchased them for their use.

Daniel raised that the research team had also considered this possibility.

Mr. [redacted] commented that this is a high risk topic.

Daniel thanked Mr. [redacted] and his colleagues for their valuable time and comments. He ensured that the research team would consider the points raised. Also, he handed out some CII conference flyers and invited OSHC colleagues to submit papers.

Appendix 4 - Notes of Meeting with BD

Research Topic:	Developing a Prototype for a Rapid Demountable Platform (RDP)
Members Present:	*Buildings Department (BD):* [redacted] (Senior Structural Engineer) *The Hong Kong Polytechnic University (PolyU):* Edmond LAM (Research Associate) Esther CHOY (Research Assistance)
Interview Date:	13th August 07 (Monday)
Interview Time:	14:30 – 16:00
Interview Venue:	Buildings Department, 16/F Pioneer Centre, 750 Nathan Road, Kowloon 28 Marble Road, North Point, Hong Kong

Further to the interview with OSHC on 6th August 07, another interview with Buildings Department has been carried out.

Mr. [redacted] advised our team should invite practitioners for workshops besides seeking comments from governmental departments.

Edmond told demonstration or workshop has been planned in Sept or Oct. Focus on the commissioning process, he walked through the flow with Mr. [redacted].

Mr. [redacted] doubted if the RDP requires certificate registration (similar to the case in bamboo scaffold) issued by the Labor Department (LD). He thought our team should go through adequate testing and approval procedures before the commencement of manufacturing. He further questioned on the purpose of the flow chart.

Edmond replied this was outlined to foresee the involvement of governmental departments or parties anticipated during the launching process and to ensure adequate preparation if license or approval was required.

Mr. [redacted] commented the flow chart was confusing at first glance. To provide greater confident to user, testing and patent procedures should be carried out in between the design and manufacturing stage. Demonstration was suggested to include in the earlier stage as the recognition of potential buyers should be a determining factor to the launching. He further asked the difference between licensed distributor and supplier.

Edmond quoted the example from TTAD. OSHC, being as a distributor, offered subsidizing scheme to buyers.

Mr. [redacted] would to know more on the subsidizing practice.

Esther added in the case of TTAD, OSHC would cover a portion of cost after the workers attended training; we would try to seek if similar proposal could work on the RDP.

Edmond explained OSHC did not reject the subsidy plan on RDP in the previous interview on 6/8, but the approval of LD must be granted beforehand.

Mr. [redacted] continued to ask about the person-in-charge on order placement and the QC control.

Edmond replied the issues should be responsible by supplier or distributor.

Mr. [redacted] questioned on the inclusion of insurance (rental or purchase) and also the responsibility issues should fall.

Edmond answered the insurance issues have been discussed within our team. The idea should be similar to the car rental scheme. He further told our team still had time to probe the issues as the RDP would not be rushing to launch right after the second stage study ending in Sept.

Mr. [redacted] said the insurance shall be considered in the manufacturing stage. He continued commented on the arrangement of flow chart. He suggested the mainstream should only include PolyU, testing, manufacturing, supplier and users while the rest components could be added as branching. He extended training on both supervisory and workforce levels should be initiated before the manufacturing stage so as to ensure the RDP was potentially accepted by users or practitioners. Also, the period of warranty should be addressed.

Edmond quoted the concern by OSHC, the availability of international standard on TTAD has given greater confident to LD's approval. Would it be a problem for the approval of RDP as no direct standard associated?

Mr. [redacted] agreed this was also one of the concerns. The case of Gondola could be an example. A series of testing procedures would undergo before the approval.

Esther added relevant loading tests would be carried out after the fabrication of RDP Prototype II.

Mr. [redacted] suggested our team should ask LD for the requirement of RDP if it did not include in any specific standards as it might be case dependent.

Edmond invited Tang to comment on the discharge of license. As previously suggested by Mr. [redacted] in OSHC, sole licensor might lack of competition in the market.

Mr. [redacted] did not have much concern on this issue. He introduced the concept of agent as a proxy of PolyU. Users and contractors could refer them for marketing issues and relevant enquiries induced.

Edmond agreed the idea was feasible. If the agency role was employed, he would like to know how LD, BD and OSHC could involve in the launching of RDP.

Mr. [redacted] said for normal practice LD would refer to relevant governmental departments for info if they did not have guideline or judgment on new product.

Edmond consulted the implementation of minor works.

Mr. [redacted] answered the levels of minor works would be divided into three categories. Minor works could provide guidelines without violating the regulations.

Edmond suggested if the RDP could belong to the simplest category with no competent person required.

Mr. [redacted] also supported the RDP could fall onto the minor works. He believed workers could handle the inspection of RDP after certain trainings. He explained certified workers were also allowed by LD while the employment of competent person would not necessary and may incur additional cost.

Edmond doubted the efficiency to request workers attending the RDP training.

Mr. [redacted] thought such kind of training could be incorporated with other nature of works in one go.

Edmond would like to know the requirement of minor work contractor.

Mr. [redacted] said that required adequate experience and went through the registration process. Although he believed competent person may not be necessary, he raised his concern on the wall strength.

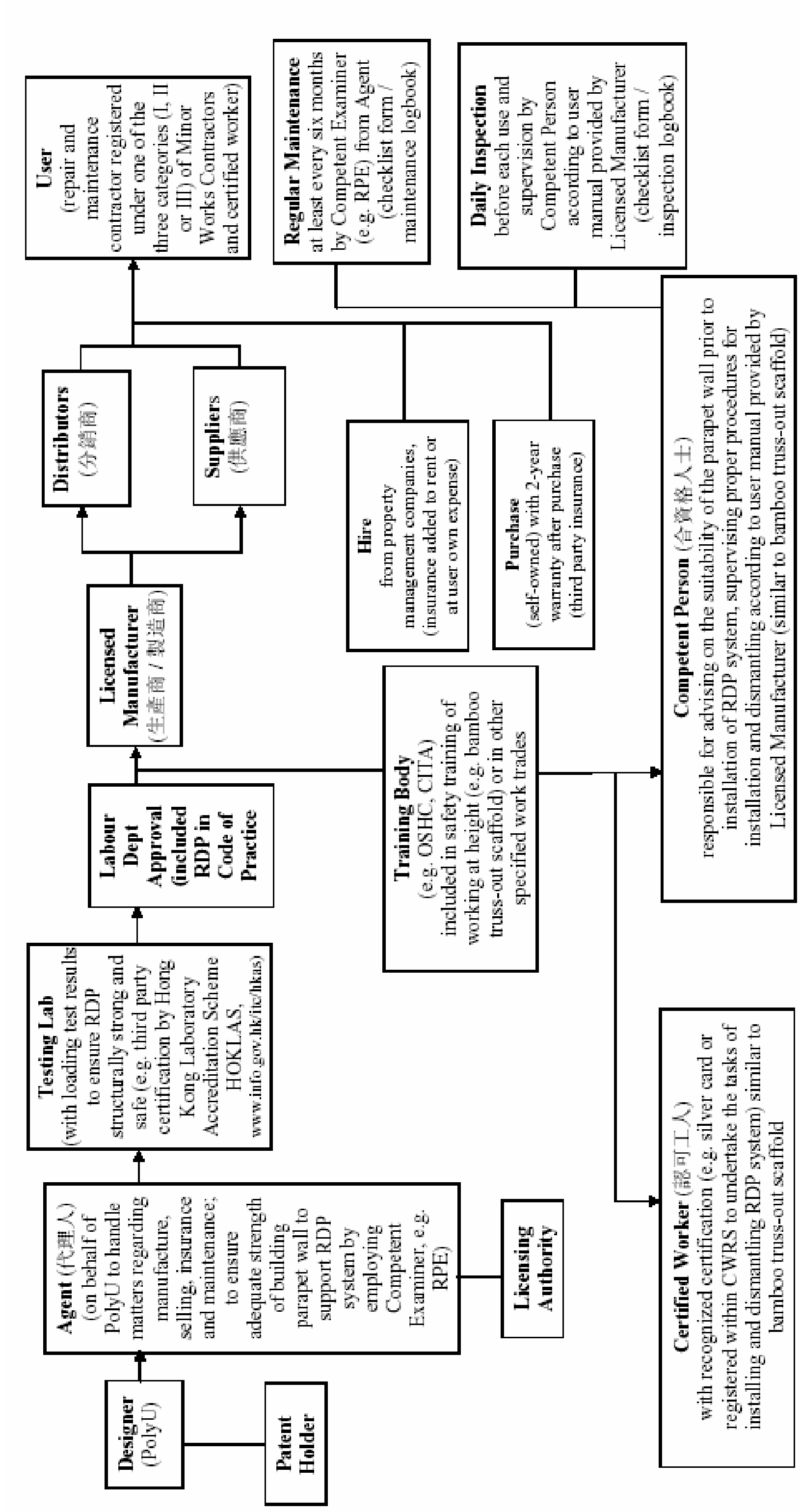
Esther asked if there were ways to sense the suitability of wall.

Mr. [redacted] said no rules could follow. He suggested this duty should be taken up by the agent and they should arrange appropriate person to perform the wall checking wherever necessary. The information of external wall should be available in BD office. Wall examination requirement and steps could be included in the installation procedures.

Edmond questioned the necessity of maintenance.

Mr. [redacted] replied LD shall have some guidelines on every approved device. This duty could also be taken up by the agent.
Edmond thanked for Tang’s comments and our team would be in touch with him for any update.

Appendix 5 – Revised Flowchart Showing the Proposed Market Launch of the RDP in Building, Construction, Repair and Maintenance Sector



Appendix 6 – Draft Table of Content for RDP Installation Procedures

Rapid Demountable Platform (RDP) 快 速 安 裝 平 台

Table of Contents

Appendix 7 – Video of RDP Prototype II Installation Process

Appendix 8 – Supporting Calculations for RDP Prototype II

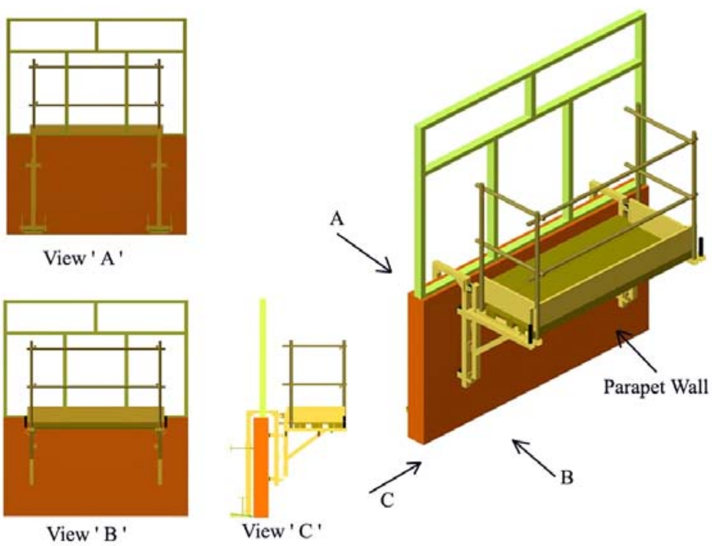
	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Structural Calculation for RDP Prototype II

For Project:

Research Project on the Stage II of Construction Safety Involving Working at Height for Residential Building Repair and Maintenance - Developing a Prototype for a Rapid Demountable Platform (RDP)



The Hong Kong Polytechnic University		
Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung	Checked by:	Date: 30/8/2007

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Introduction:

The Design Calculation presents the structural design and analysis of RDP Prototype II. Computer programmes SAP2000 and ABAQUS were used for the structural analysis of RDP Prototype II . SAP2000 results were used in the members design. ABAQUS results was used in connection design.

There are two sets of Triangular Frame and U-Frame supporting the RDP. In the numerical model, one set of Triangular Frame and U-Frame was modeled. The Models were built according to the dimensions and the boundary conditions shown in Figs 1 to 4. The design loadings used in the design were shown in Fig. 5. Fig. 6 shows the load path of RDP II. In the structural analysis, the Base Supports was not modeled. The base supports were assumed to vertical force only. And this is on the safe side. As sections size of the base support is larger than those of the U-Frame, there is no checking for the base supports members.

SAP2000 Numerical Models were generated with the following conditions:

1. U-Frame fixed to Base Support with P1 hole and Triangular-Frame fixed at Normal Level as shown.
2. U-Frame fixed to Base Support with P1 hole and Triangular-Frame fixed at Lower Level.
3. U-Frame fixed to Base Support with P2 hole and Triangular-Frame fixed at Normal Level.
4. U-Frame fixed to Base Support with P2 hole and Triangular-Frame fixed at Lower Level.
5. U-Frame fixed to Base Support with P2 hole and Triangular-Frame fixed at Normal Level. (P-delta effect was considered)

ABAQUS results was generated with the condition that U-Frame fixed to Base Support with P2 hole and Triangular-Frame fixed at Normal Level.

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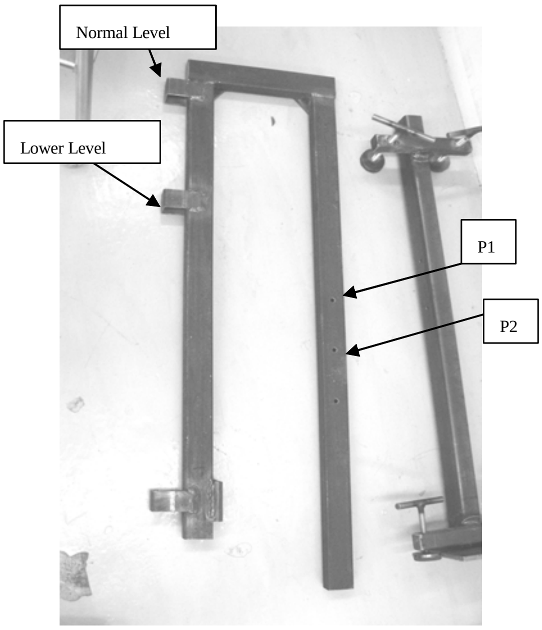
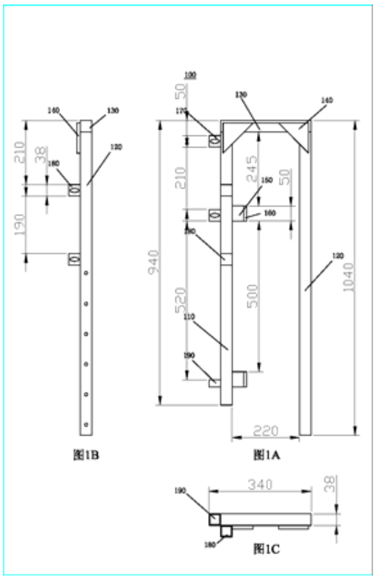
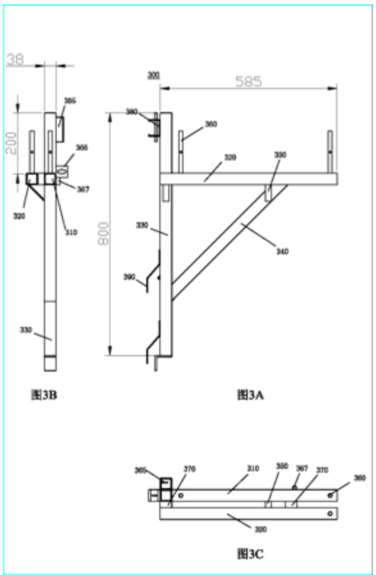
Ref.	Details	Output/Action
	 **Fig 1. Definition of levels**   **Fig 2. Drawing of U-Frame** **Fig 3. Drawing of Triangular Frame**	

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
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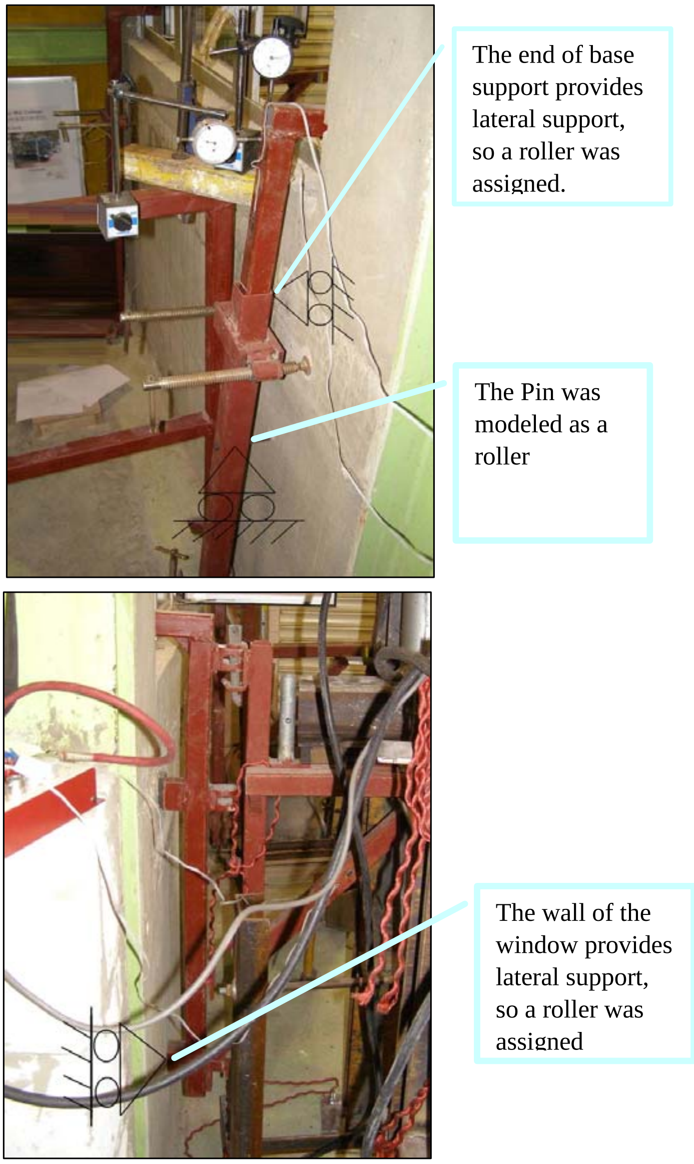
Ref.	Details	Output/Action
	 **Fig 4.** **<u>Boundary Conditions</u>**	

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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

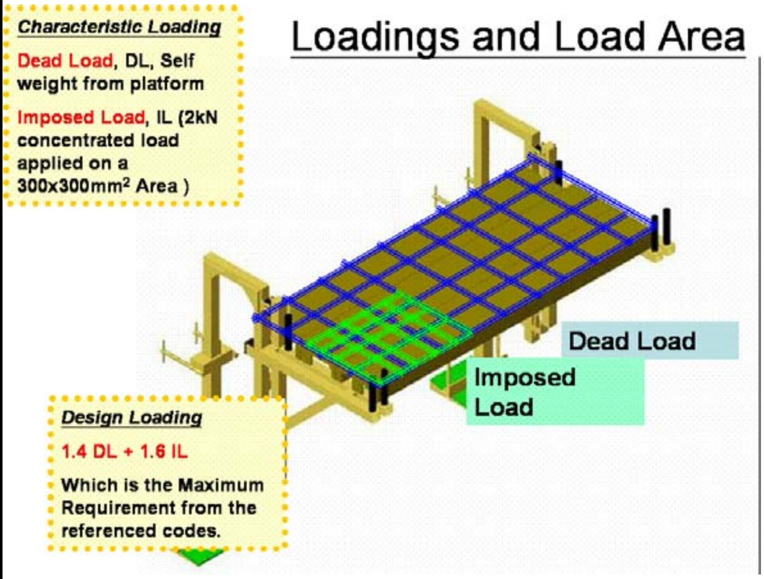

Fig 5. Applied loadings

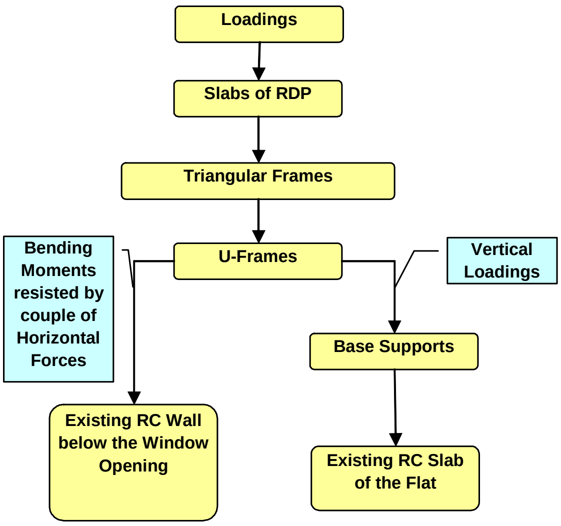

Fig 6. Load Path of RDP

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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
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Ref.	Details	Output/Action
	<u>Design Code:</u> ***The Design Calculation was based on the requirements of*** 1. Code of Practice for The Structural Use of Steel 2005, Buildings Department, Hong Kong (Ref. 1) 2. Building (Construction) Regulations (Ref. 2) 3. Guidelines on the Design and Construction of Bamboo Scaffolds : 2006 , Buildings Department (Ref. 3) 4. Code of Practice for Bamboo Scaffolding Safety: 2001 , Occupational Safety and Health Branch, Labour Department (Ref. 4) 5. Code of Practice for Metal Scaffolding Safety: 2001 , Occupational Safety and Health Branch, Labour Department (Ref. 5)	

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	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
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Ref.	Details	Output/Action

Design Assumptions and Parameters:

Assumptions:

- Gravity loads will be transferred to supporting steel frame, and then be transferred to reinforced concrete wall at the window opening.
- The reinforced concrete wall at the window opening, should be structurally sound and safe for the use of RDP.
- Wind load: no calculation is required.
- The column withstands horizontal design live load 0.75 kN/m acting at 1.1m level from ground only.
- All Structural Steel to be Grade 50 Steel.
- All connection of steel members provided with 4mm fillet weld all round with welding electrode E51 refer to BS639.
- All Bolts used are M8 Grade 8.8 bolts.
- Dimension of RDP Prototype II Platform - **585mm x 1500mm**

Sections Size:

No.	Location	Material	Section
1.	U-Frames	Grade 50 Steel	50x30x3mm RHS
2.	Triangular Frames	Grade 50 Steel	25x25x2.5mm SHS
3.	Base Supports	Grade 50 Steel	60x40x3mm RHS

Materials Allowable Stresses:

Ref.	Details		
(Ref. 1) Clause 3.1.2	• **Structural Steel (Grade 50)**		
	p_y =	**355**	**MPa**
	Density =	**7860**	**kg/m^3**
	Modulus of elasticity =	**205000**	**MPa**
(Ref. 1) Clause 6.6	• **Fillet Weld of Steel, p_w electrode strength to BS639, E51**	**255**	**MPa**
(Ref. 1)	• **M8 Bolt Tensile Strength, Grade 8.8**		
Table 2.8	**p_t =**	**450.0**	**MPa**
Table 2.4	**p_s =**	**375.0**	**MPa**
Table 6.2	**p_{bb} =**	**1035.0**	**MPa**
(Ref. 1) Clause 6.3 Table 32			

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
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Ref.	Details	Output/Action
	Characteristic Loadings:	
	• Characteristic Imposed Live Load — 2 kN/m^2	
	• Density of Steel — 7860 kg/m^3	
	• **Characteristic Dead Load from Slab and above** — 0.463 kN/m^2	
	(Equivalent to 6mm Steel Plate)	
	Load area of RDP Prototype II is **585mm x 1500mm**	
	Characteristic Dead Load from act on Triangular — **0.347 kN/m**	
	(=0.463*1.5/2)	
	• **Characteristic Imposed Load, LL** — 2.000 kN/m^2	
	Load area of RDP Prototype II is **585mm x 1500mm**	
	Characteristic Imposed Load from act on Triangular — **1.500 kN/m**	
	Design Loading:	
(Ref. 1)	Ultimate Limit State: 1.4 DL + 1.6 LL	
	(For Structural Members Checking)	
(Ref. 3)	Ultimate Limit State: 1.5 DL + 1.5 LL	
	(For Structural Members Checking)	
	Notes: As Imposed Load is larger therefore, 1.4DL + 1.6LL will be more conservative.	
	==> ULS. Design Load = 1.4DL+1.6LL	
	Serviceability Limit State: 1.0DL+1.0LL	
	(For Deflection Checking)	

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Ref.	Details	Output/Action

Design Calculations (SAP2000 Models):

Sections Properties:

Section	Area (mm^2)	I_{xx} (mm^4)	Z_{xx} (mm^3)	S_{xx} (mm^3)	r_{yy} (mm)
50x30x3mm RHS	440	139000	5540	7010	11.7
25x25x2.5mm SHS	222	18500	1480	1860	9.14
60x40x3mm RHS	560	269000	8960	11100	15.9

Classification of cross sections

(Ref. 1) Table 7.2 — Table 7.2
Limiting width-to-thickness ratios for CHS and RHS.

Compression Element

Flange: **Compression due to bending**
b/t limiting value = 28ε but $\leq 80\varepsilon$-d/t ==> Class 1

Web: **Neutal axis at mid-depth**
d/t limiting value = 64ε ==> Class 1

For p_y = 355 N/mm^2

$\varepsilon = \sqrt{(275/p_y)}$ = 0.8801

28ε = 24.6

64ε = 56.3

Section	d/t	b/t	80ε-d/t	Class	Section
50x30x3mm RHS	13.7	7.00	56.71	Class 1	Plastic
25x25x2.5mm SHS	7.00	7.00	63.41	Class 1	Plastic
60x40x3mm RHS	17.00	10.30	53.41	Class 1	Plastic

(Ref. 1) Clause 8.3.5.1 Table 8.2

If SHS or Limiting value of L_E/r_y for RHS less than the value shown in Table 8.2, the section need not be checked in lateral-torsional buckling.

Ratio

D/B = 50/30 = 1.67 Limit Value = $435\varepsilon^2$

D/B = 60/40 = 1.5 Limit Value = $515\varepsilon^2$

Section	r_{yy} (mm)	L_E(mm)	L_E/r_{yy}	L_E/r_{yy} Limit Value from Table 8.2	
50x30x3mm RHS	11.7	355.00	30.34	336.97	
25x25x2.5mm SHS	SHS need not be checked in Lateral-torsional buckling				
60x40x3mm RHS	15.9	900.00	56.60	398.94	

==> No need check for lateral torsional buckling

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Ref.	Details	Output/Action

(Ref. 1)
Clause 8.2.2

Moment Capacity
(Low shear condtion V< 0.6 shear capacity Vc.)

For Class 1 plastic sections
$M_c = p_y S < 1.2\, p_y\, Z$

Section	py (MPa)	Sxx (mm3)	Zxx (mm3)	pyS (kNm)	1.2 py Zxx(kNm)
50x30x3mm RHS	355	7010	5540	2.49	2.36
25x25x2.5mm SHS	355	1860	1480	0.66	0.63
60x40x3mm RHS	355	11100	8960	3.94	3.82

Section	Mc (kNm)
50x30x3mm RHS	**2.36**
25x25x2.5mm SHS	**0.63**
60x40x3mm RHS	**3.82**

Mc = Min (PyS, 1.2PyZxx)

Ref. 1
Clause
8.9.1

8.9.1 Cross-section capacity

Except for Class 4 slender cross-sections, the cross-section capacity can be checked as,

$$\frac{F_c}{A_g p_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}} \le 1 \qquad (8.78)$$

in which M_x and M_y are the design moments about the x- and y-axes. M_{cx} and M_{cy} are the moment capacities about the x- and y-axes.

Deflection Checking
Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Case	Tip Deflection (mm)
Lower Lower	7.928
Lower Normal	14.893
Upper Lower	3.700
Upper Normal	8.070

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Ref.	Details	Output/Action

Member Force Summary

File: P2- Lower level

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Member No.	P	V2	V3	T	M2	M3
	KN	KN	KN	KN-m	KN-m	KN-m
U-Frame						
1	3.257	-4.037	0.000	0.000	0.000	1.404
7	0.003	0.000	0.000	0.000	0.000	0.000
11	4.037	-3.266	0.000	0.000	0.000	1.546
25	-3.301	0.000	0.000	0.000	0.000	0.000
26	-3.278	4.037	0.000	0.000	0.000	-0.626
Triangular Frame						
5	3.215	2.925	0.000	0.000	0.000	0.368
6	2.673	-3.089	0.000	0.000	0.000	-0.264
8	0.004	0.000	0.000	0.000	0.000	0.000
9	0.001	0.000	0.000	0.000	0.000	0.000
12	0.000	1.648	0.000	0.000	0.000	-0.134
13	3.089	0.527	0.000	0.000	0.000	-0.138
16	-4.069	-0.299	0.000	0.000	0.000	0.098
Connection						
2	2.925	-3.216	0.000	0.000	0.000	0.304
14	-2.184	-1.945	0.000	0.000	0.000	-0.234

Local Capacity Check

Ref. 1
Clause
8.9.1

Member No.	Ag py	Mc	P/(AgPy)	M/Mc	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	156	2.360	0.0209	0.5948	**0.6156**	OK
7	156	2.360	0.0000	0.0000	**0.0000**	OK
11	156	2.360	0.0258	0.6552	**0.6810**	OK
25	156	2.360	0.0211	0.0000	**0.0211**	OK
26	156	2.360	0.0210	0.2652	**0.2862**	OK
Triangular Frame						
5	79	0.630	0.0408	0.5837	**0.6245**	OK
6	79	0.630	0.0339	0.4181	**0.4520**	OK
8	79	0.630	0.0001	0.0000	**0.0001**	OK
9	79	0.630	0.0000	0.0000	**0.0000**	OK
12	79	0.630	0.0000	0.2130	**0.2130**	OK
13	79	0.630	0.0392	0.2182	**0.2574**	OK
16	79	0.630	0.0516	0.1553	**0.2069**	OK

	The Hong Kong Polytechnic University		
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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
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Ref.	Details	Output/Action

Overall Buckling Check

Evaluate P_{cy} & assume an effective length

For **50x30x3mm RHS**

$L_E =$ 1000 mm K = 1.0

∴ $r_y =$ 11.7 mm

∴ $L_E/r_y =$ 85.5

∴ $p_c =$ 214 MPa

For **25x25x2.5mm SHS**

$L_E =$ 800 mm K = 1.0

∴ $r_y =$ 9.14 mm

Ref. 1 ∴ $L_E/r_y =$ 87.5

Table 8.8(a) ∴ $p_c =$ 208 MPa

Ref. 1

Clause 11.5.5.2

Member No.	$\overline{P_c}$	M_{cx}	$F_c / \overline{P_c}$	M_x / M_{cx}	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	94	1.967	0.0346	0.7137	**0.7483**	OK
7	94	1.967	0.0000	0.0000	**0.0000**	OK
11	94	1.967	0.0429	0.7862	**0.8291**	OK
25	94	1.967	0.0351	0.0000	**0.0351**	OK
26	94	1.967	0.0348	0.3183	**0.3531**	OK
Triangular Frame						
5	46	0.525	0.0696	0.7004	**0.7700**	OK
6	46	0.525	0.0579	0.5017	**0.5596**	OK
8	46	0.525	0.0001	0.0000	**0.0001**	OK
9	46	0.525	0.0000	0.0000	**0.0000**	OK
12	46	0.525	0.0000	0.2556	**0.2556**	OK
13	46	0.525	0.0669	0.2619	**0.3288**	OK
16	46	0.525	0.0881	0.1863	**0.2745**	OK

Where

$\boxed{\overline{P_c} = p_c \times A}$

$\boxed{M_{cx} = p_y \times Z_x}$

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	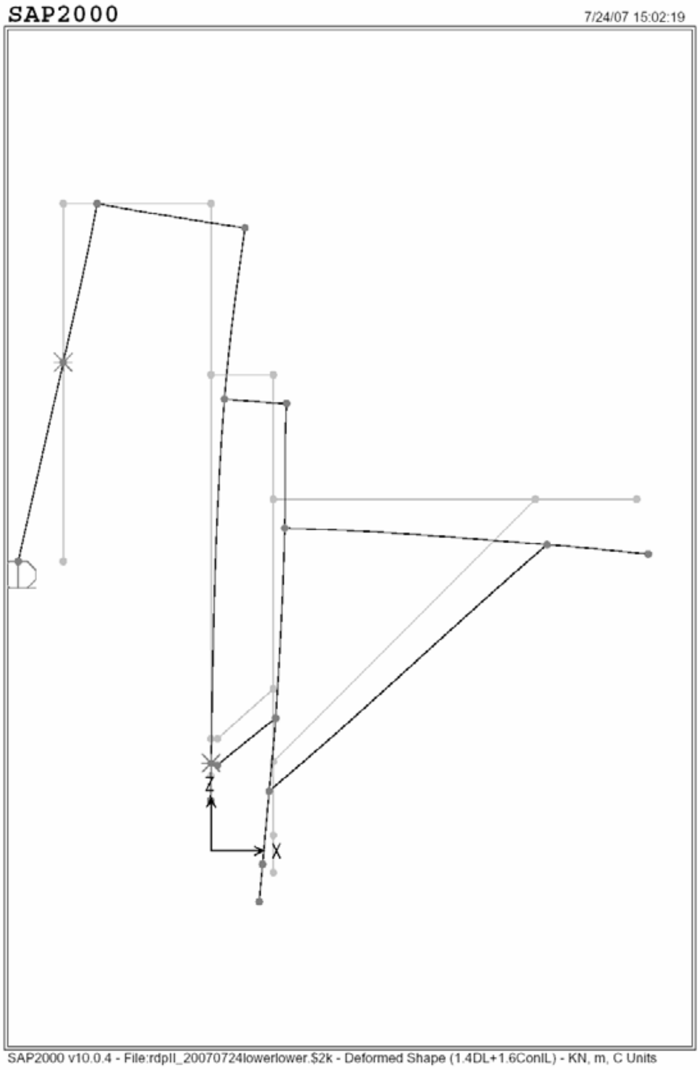	

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Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung	Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Member Force Summary

File: P2 - Normal level

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Member No.	P	V2	V3	T	M2	M3
	KN	KN	KN	KN-m	KN-m	KN-m
U-Frame						
3	0.039	-1.927	0.000	0.000	0.000	1.465
7	0.003	0.000	0.000	0.000	0.000	0.000
11	4.037	-3.266	0.000	0.000	0.000	1.546
25	-3.286	0.000	0.000	0.000	0.000	0.000
26	-3.278	4.037	0.000	0.000	0.000	-0.626
Triangular Frame						
5	3.215	2.110	0.000	0.000	0.000	0.388
6	3.400	-0.803	0.000	0.000	0.000	0.251
8	0.007	2.110	0.000	0.000	0.000	0.418
9	0.001	0.000	0.000	0.000	0.000	0.000
12	0.000	1.648	0.000	0.000	0.000	-0.134
13	2.913	-1.730	0.000	0.000	0.000	-0.166
16	-4.459	0.338	0.000	0.000	0.000	-0.167
Connection						
2	2.110	-3.216	0.000	0.000	0.000	0.323
14	-1.577	-1.402	0.000	0.000	0.000	0.000

Local Capacity Check

Ref. 1 Clause 8.9.1

Member No.	Ag py	Mc	P/(AgPy)	M/Mc	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
3	156	2.360	0.0002	0.6205	**0.6208**	OK
7	156	2.360	0.0000	0.0000	**0.0000**	OK
11	156	2.360	0.0258	0.6552	**0.6810**	OK
25	156	2.360	0.0210	0.0000	**0.0210**	OK
26	156	2.360	0.0210	0.2652	**0.2862**	OK
Triangular Frame						
5	79	0.630	0.0408	0.6146	**0.6554**	OK
6	79	0.630	0.0431	0.3980	**0.4411**	OK
8	79	0.630	0.0001	0.6628	**0.6629**	OK
9	79	0.630	0.0000	0.0000	**0.0000**	OK
12	79	0.630	0.0000	0.2130	**0.2130**	OK
13	79	0.630	0.0370	0.2635	**0.3004**	OK
16	79	0.630	0.0566	0.2650	**0.3216**	OK

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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
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Ref.	Details	Output/Action

Overall Buckling Check

Evaluate P_{cy} & assume an effective length

For **50x30x3mm RHS**

L_E = 1000 mm K = 1.0

∴ r_y = 11.7 mm

∴ L_E/r_y = 85.5

∴ p_c = 214 MPa

For **25x25x2.5mm SHS**

L_E = 800 mm K = 1.0

∴ r_y = 9.14 mm

Ref. 1 ∴ L_E/r_y = 87.5

Table 8.8(a) ∴ p_c = 208 MPa

Where

$\overline{P_c} = p_c \times A$

$M_{cx} = p_y \times Z_x$

Ref. 1

Clause 11.5.5.2

Member No.	$\overline{P_c}$	M_{cx}	$F_c / \overline{P_c}$	M_x / M_{cx}	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	94	1.967	0.0004	0.7446	**0.7451**	OK
7	94	1.967	0.0000	0.0000	**0.0000**	OK
11	94	1.967	0.0429	0.7862	**0.8291**	OK
25	94	1.967	0.0349	0.0000	**0.0349**	OK
26	94	1.967	0.0348	0.3183	**0.3531**	OK
Triangular Frame						
5	46	0.525	0.0696	0.7375	**0.8072**	OK
6	46	0.525	0.0736	0.4775	**0.5512**	OK
8	46	0.525	0.0002	0.7954	**0.7956**	OK
9	46	0.525	0.0000	0.0000	**0.0000**	OK
12	46	0.525	0.0000	0.2556	**0.2556**	OK
13	46	0.525	0.0631	0.3161	**0.3792**	OK
16	46	0.525	0.0966	0.3180	**0.4146**	OK

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	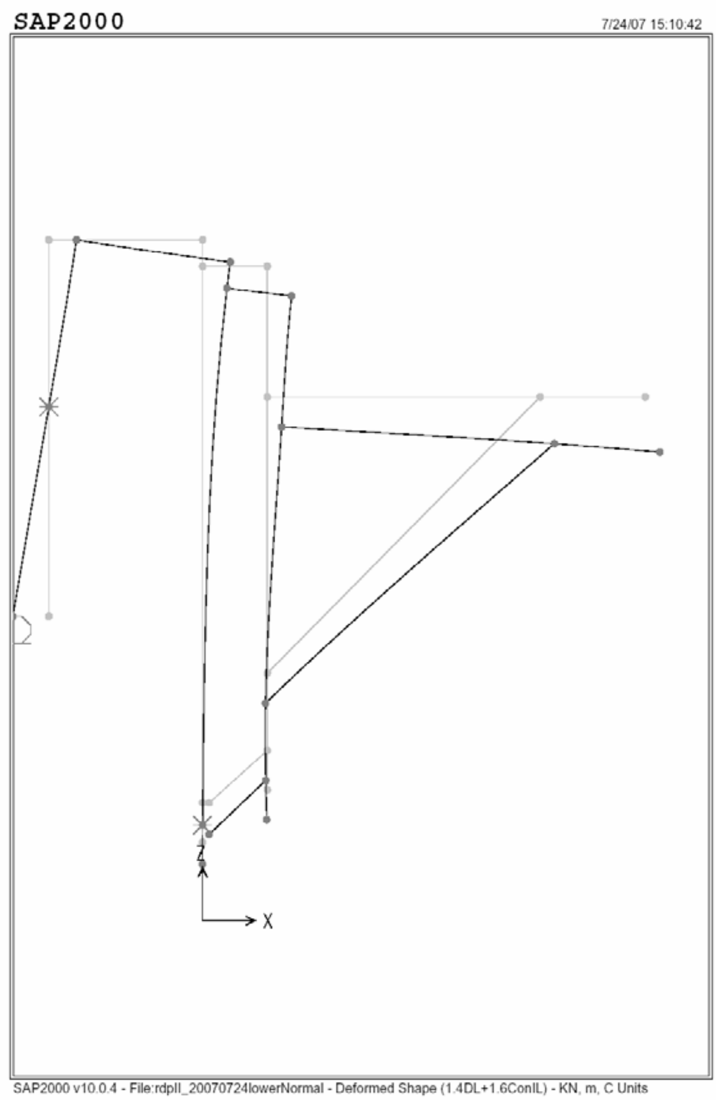	

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Ref.	Details	Output/Action

Member Force Summary

File: P1 - Lower level

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Member No.	P	V2	V3	T	M2	M3
	KN	KN	KN	KN-m	KN-m	KN-m
U-Frame						
1	3.257	-3.465	0.000	0.000	0.000	0.968
7	0.003	0.000	0.000	0.000	0.000	0.000
11	3.465	-3.266	0.000	0.000	0.000	1.054
25	-3.281	0.000	0.000	0.000	0.000	0.000
26	-3.278	3.465	0.000	0.000	0.000	-0.191
Triangular Frame						
5	3.215	2.858	0.000	0.000	0.000	0.329
6	2.637	-3.065	0.000	0.000	0.000	-0.259
8	0.004	0.000	0.000	0.000	0.000	0.000
9	0.001	0.000	0.000	0.000	0.000	0.000
12	0.000	1.648	0.000	0.000	0.000	-0.134
13	3.065	0.563	0.000	0.000	0.000	-0.150
16	-4.027	-0.308	0.000	0.000	0.000	0.100
Connection						
2	2.858	-3.216	0.000	0.000	0.000	0.265
14	-2.134	-1.901	0.000	0.000	0.000	-0.229

Ref. 1 Clause 8.9.1

Local Capacity Check

Member No.	Ag py	Mc	P/(AgPy)	M/Mc	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	156	2.360	0.0209	0.4103	**0.4312**	OK
7	156	2.360	0.0000	0.0000	**0.0000**	OK
11	156	2.360	0.0222	0.4465	**0.4687**	OK
25	156	2.360	0.0210	0.0000	**0.0210**	OK
26	156	2.360	0.0210	0.0808	**0.1018**	OK
Triangular Frame						
5	79	0.630	0.0408	0.5218	**0.5626**	OK
6	79	0.630	0.0335	0.4100	**0.4435**	OK
8	79	0.630	0.0001	0.0000	**0.0001**	OK
9	79	0.630	0.0000	0.0000	**0.0000**	OK
12	79	0.630	0.0000	0.2130	**0.2130**	OK
13	79	0.630	0.0389	0.2376	**0.2765**	OK
16	79	0.630	0.0511	0.1589	**0.2100**	OK

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Overall Buckling Check

Evaluate P_{cy} & assume an effective length

For **50x30x3mm RHS**

L_E = 1000 mm K = 1.0

∴ r_y = 11.7 mm

∴ L_E/r_y = 85.5

∴ p_c = 214 MPa

For **25x25x2.5mm SHS**

L_E = 800 mm K = 1.0

∴ r_y = 9.14 mm

Ref. 1 ∴ L_E/r_y = 87.5

Table 8.8(a) ∴ p_c = 208 MPa

Ref. 1

Clause 11.5.5.2

Member No.	$\overline{P_c}$	M_{cx}	$F_c / \overline{P_c}$	M_x / M_{cx}	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	94	1.967	0.0346	0.4924	**0.5270**	OK
7	94	1.967	0.0000	0.0000	**0.0000**	OK
11	94	1.967	0.0368	0.5358	**0.5726**	OK
25	94	1.967	0.0348	0.0000	**0.0348**	OK
26	94	1.967	0.0348	0.0970	**0.1318**	OK
Triangular Frame						
5	46	0.525	0.0696	0.6262	**0.6958**	OK
6	46	0.525	0.0571	0.4920	**0.5491**	OK
8	46	0.525	0.0001	0.0000	**0.0001**	OK
9	46	0.525	0.0000	0.0000	**0.0000**	OK
12	46	0.525	0.0000	0.2556	**0.2556**	OK
13	46	0.525	0.0664	0.2851	**0.3515**	OK
16	46	0.525	0.0872	0.1907	**0.2779**	OK

Where

$\overline{P_c} = p_c \times A$

$M_{cx} = p_y \times Z_x$

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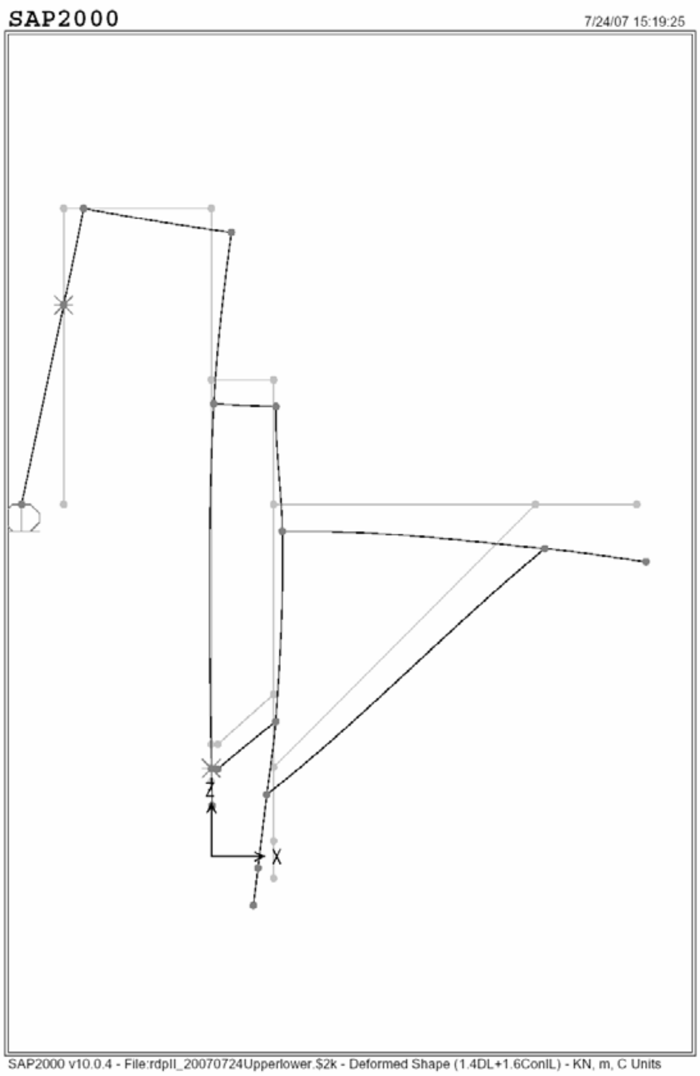
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action
		

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	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action
Ref. 1 Clause 8.9.1		

Member Force Summary

File: P1 - Normal level

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Member No.	P	V2	V3	T	M2	M3
	KN	KN	KN	KN-m	KN-m	KN-m
U-Frame						
3	0.039	-1.431	0.000	0.000	0.000	1.088
7	0.003	0.000	0.000	0.000	0.000	0.000
11	3.465	-3.266	0.000	0.000	0.000	1.054
25	-3.288	0.000	0.000	0.000	0.000	0.000
26	-3.278	3.465	0.000	0.000	0.000	-0.191
Triangular Frame						
5	3.215	2.033	0.000	0.000	0.000	0.324
6	3.315	-0.849	0.000	0.000	0.000	0.249
8	0.007	2.033	0.000	0.000	0.000	0.403
9	0.001	0.000	0.000	0.000	0.000	0.000
12	0.000	1.648	0.000	0.000	0.000	-0.134
13	2.882	-1.645	0.000	0.000	0.000	-0.157
16	-4.377	0.301	0.000	0.000	0.000	-0.154
Connection						
2	2.033	-3.216	0.000	0.000	0.000	0.260
14	-1.518	-1.353	0.000	0.000	0.000	-0.163

Local Capacity Check

Member No.	Ag py	Mc	P/(AgPy)	M/Mc	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
3	156	2.360	0.0002	0.4609	**0.4611**	OK
7	156	2.360	0.0000	0.0000	**0.0000**	OK
11	156	2.360	0.0222	0.4465	**0.4687**	OK
25	156	2.360	0.0210	0.0000	**0.0210**	OK
26	156	2.360	0.0210	0.0808	**0.1018**	OK
Triangular Frame						
5	79	0.630	0.0408	0.5145	**0.5553**	OK
6	79	0.630	0.0421	0.3949	**0.4370**	OK
8	79	0.630	0.0001	0.6387	**0.6388**	OK
9	79	0.630	0.0000	0.0000	**0.0000**	OK
12	79	0.630	0.0000	0.2130	**0.2130**	OK
13	79	0.630	0.0366	0.2489	**0.2854**	OK
16	79	0.630	0.0555	0.2438	**0.2993**	OK

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Overall Buckling Check

Evaluate P_{cy} & assume an effective length

For **50x30x3mm RHS**

L_E = 1000 mm K = 1.0

∴ r_y = 11.7 mm

∴ L_E/r_y = 85.5

∴ p_c = 214 MPa

For **25x25x2.5mm SHS**

L_E = 800 mm K = 1.0

∴ r_y = 9.14 mm

Ref. 1 ∴ L_E/r_y = 87.5

Table 8.8(a) ∴ p_c = 208 MPa

Ref. 1

Clause 11.5.5.2

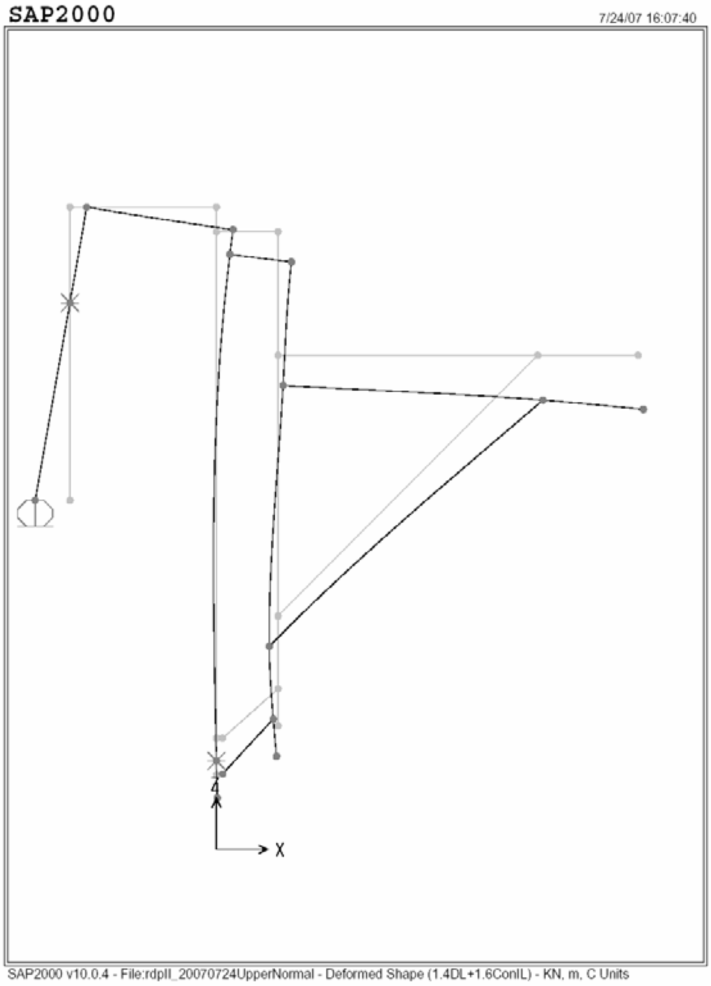
Member No.	$\overline{P_c}$	M_{cx}	$F_c/\overline{P_c}$	M_x/M_{cx}	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	94	1.967	0.0004	0.5531	**0.5535**	OK
7	94	1.967	0.0000	0.0000	**0.0000**	OK
11	94	1.967	0.0368	0.5358	**0.5726**	OK
25	94	1.967	0.0349	0.0000	**0.0349**	OK
26	94	1.967	0.0348	0.0970	**0.1318**	OK
Triangular Frame						
5	46	0.525	0.0696	0.6174	**0.6871**	OK
6	46	0.525	0.0718	0.4739	**0.5457**	OK
8	46	0.525	0.0002	0.7665	**0.7666**	OK
9	46	0.525	0.0000	0.0000	**0.0000**	OK
12	46	0.525	0.0000	0.2556	**0.2556**	OK
13	46	0.525	0.0624	0.2986	**0.3610**	OK
16	46	0.525	0.0948	0.2925	**0.3873**	OK

Where

$$\boxed{\overline{P_c} = p_c \times A}$$

$$\boxed{M_{cx} = p_y \times Z_x}$$

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action
		

The Hong Kong Polytechnic University		
Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung	Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Member Force Summary

File: P2 - Normal Level (P-delta effect)

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

Member No.	P	V2	V3	T	M2	M3
	KN	KN	KN	KN-m	KN-m	KN-m
U-Frame						
3	0.026	-1.976	0.000	0.000	0.000	1.502
7	0.003	0.000	0.000	0.000	0.000	0.000
11	4.177	-3.175	0.000	0.000	0.000	1.612
25	-3.314	0.124	0.000	0.000	0.000	-0.040
26	-3.165	4.198	0.000	0.000	0.000	-0.691
Triangular Frame						
5	3.199	2.151	0.000	0.000	0.000	0.397
6	3.397	-0.805	0.000	0.000	0.000	-0.088
8	0.011	2.117	0.000	0.000	0.000	0.420
9	0.002	0.000	0.000	0.000	0.000	0.000
12	0.015	1.649	0.000	0.000	0.000	0.000
13	2.931	-1.735	0.000	0.000	0.000	-0.167
16	-4.472	0.341	0.000	0.000	0.000	-0.168
Connection						
2	2.177	-3.184	0.000	0.000	0.000	0.334
14	-1.572	-1.418	0.000	0.000	0.000	-0.171

Ref. 1 Clause 8.9.1

Local Capacity Check

Member No.	Ag py	Mc	P/(AgPy)	M/Mc	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
3	156	2.360	0.0002	0.6363	**0.6365**	OK
7	156	2.360	0.0000	0.0000	**0.0000**	OK
11	156	2.360	0.0267	0.6829	**0.7097**	OK
25	156	2.360	0.0212	0.0168	**0.0380**	OK
26	156	2.360	0.0203	0.2926	**0.3128**	OK
Triangular Frame						
5	79	0.630	0.0406	0.6298	**0.6704**	OK
6	79	0.630	0.0431	0.1401	**0.1832**	OK
8	79	0.630	0.0001	0.6668	**0.6669**	OK
9	79	0.630	0.0000	0.0000	**0.0000**	OK
12	79	0.630	0.0002	0.0000	**0.0002**	OK
13	79	0.630	0.0372	0.2647	**0.3019**	OK
16	79	0.630	0.0567	0.2669	**0.3237**	OK

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Overall Buckling Check

Evaluate P_{cy} & assume an effective length

For **50x30x3mm RHS**

L_E = 1000 mm K = 1.0

∴ r_y = 11.7 mm

∴ L_E/r_y = 85.5

∴ p_c = 214 MPa

For **25x25x2.5mm SHS**

L_E = 800 mm K = 1.0

∴ r_y = 9.14 mm

Ref. 1 ∴ L_E/r_y = 87.5

Table 8.8(a) ∴ p_c = 208 MPa

Ref. 1

Clause 11.5.5.2

Member No.	$\overline{P_c}$	M_{cx}	$F_c/\overline{P_c}$	M_x/M_{cx}	Σ	
	kN	kNm	(A)	(B)	(A) + (B)	Remark
U-Frame						
1	94	1.967	0.0003	0.7636	**0.7638**	OK
7	94	1.967	0.0000	0.0000	**0.0000**	OK
11	94	1.967	0.0444	0.8195	**0.8639**	OK
25	94	1.967	0.0352	0.0202	**0.0554**	OK
26	94	1.967	0.0336	0.3511	**0.3847**	OK
Triangular Frame						
5	46	0.525	0.0693	0.7558	**0.8251**	OK
6	46	0.525	0.0736	0.1681	**0.2416**	OK
8	46	0.525	0.0002	0.8002	**0.8004**	OK
9	46	0.525	0.0000	0.0000	**0.0000**	OK
12	46	0.525	0.0003	0.0000	**0.0003**	OK
13	46	0.525	0.0635	0.3177	**0.3811**	OK
16	46	0.525	0.0968	0.3203	**0.4172**	OK

Where

$\boxed{\overline{P_c} = p_c \times A}$

$\boxed{M_{cx} = p_y \times Z_x}$

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Deflection Checking (SAP2000):

Output C 1.0DL + 1.0LL Concentrated Imposed Load

Case	Tip Deflection (mm)
P1 Lower	2.910
P1 Normal	6.160
P2 Lower	5.590
P2 Normal	10.680
P2 Normal (P-delta	10.810

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Design Calculations Example:

Member checking of 50x30x3mm RHS

Properties:

Area (mm^2) =	440	d/t =	13.7
I_{xx} (mm^4) =	139000	b/t =	7
Z_{xx} (mm^3) =	5540	80 ε - d/t =	56.71
S_{xx} (mm^3) =	7010		
r_{yy} (mm) =	11.7		

Classification of cross sections:

Ref. 1
Table 7.2

Limiting width-to-thickness ratios for CHS and RHS.
For Compression Element
Flange: Compression due to bending
b/t limiting value = 28 ε
= 24.6
where $\varepsilon = \sqrt{(275/355)}$ = 0.8801

b/t = 7 < 28 ε
==> Class 1 ==> Plastic Section

Web: Neutral axis at mid-depth
d/t limiting value = 64 ε
= 56.3
where $\varepsilon = \sqrt{(275/355)}$ = 0.8801

d/t = 13.7 < 64 ε = 56.3
$\leq$80 ε -d/t = 56.71
==> Class 1 ==> Plastic Section
$r_1 = F_c / (2\ d\ t\ p_{yw})$
64 ε /(1+0.6r_1) but $\geqq$40ε
= (40)(0.8801)
= 35
d/t = 13.7 ==> OK

Ref.1
Clause 8.3.5.1
Table 8.2

If SHS or Limiting value of L_E/r_y for RHS less than the value shown in Table 8.2, the section need not be checked in lateral-torsional buckling.
Ratio
D/B = 50/30 = 1.67 Limit Value = 435ε^2
==> No need check for lateral torsional buckling

	The Hong Kong Polytechnic University		
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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action
Ref. 1 Clause 8.9.1	**Local Capacity** **8.9.1 Cross-section capacity** Except for Class 4 slender cross-sections, the cross-section capacity can be checked as, $\frac{F_c}{A_g p_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}} \leq 1$ (8.78) in which M_x and M_y are the design moments about the x- and y-axes. M_{cx} and M_{cy} are the moment capacities about the x- and y-axes. **Element:** 11 **Case:** P-delta effect **Section Size:** **50x30x3mm RHS** **From SAP2000 Analysis Output as shown in Page 24** Axial Force, F_c = 4.177 kN Shear Force, V= 3.175 kN Major Moment, M_x = 1.6117 kNm Minor Moment, M_y = 0 kNm **Properties of 50x30x3mm RHS :** Area (mm^2) = 440 d/t = 13.7 I_{xx} (mm^4) = 139000 b/t = 7 Z_{xx} (mm^3) = 5540 80 ε - d/t = 56.71 S_{xx} (mm^3) = 7010 py = 355 MPa r_{xx} (mm) = 11.7 F_c/ (A_g p_c) = 0.0444 M_x/ M_{cx}= 0.6829 M_y/ M_{cy}= 0	
Ref. 1 Clause 8.9.1 Eq. 8.78	Mc = Min(PyS, 1.2PyZxx) = 2.36 kNm $\frac{F_c}{A_g p_y} + \frac{M_x}{M_{cx}} + \frac{M_y}{M_{cy}}$ = 0.73 ≤ 1	==> OK

	The Hong Kong Polytechnic University		
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	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Overall Buckling Check (Non-sway)

$$\frac{F_c}{P_c} + \frac{m_x M_x}{M_{cx}} + \frac{m_y M_y}{M_{cy}} \leq 1$$

Where M_y = 0.00

$$\frac{F_c}{P_{cy}} + \frac{m_{LT} M_{LT}}{M_b} + \frac{m_y M_y}{M_{cy}} \leq 1$$

Assume m_x & m_{LT} = 1.0 (Conservative).

$M_b = M_{cx}$ ==> No need to check Lateral Torsional Buckling for the RHS members

$\therefore$ Evaluate P_{cy} & assume an effective length

L_E = 1000mm K = 1.0

$\therefore$ r_y = 11.7 mm

$\therefore$ L_E/r_y = 85.5

$\therefore$ p_c = 214 MPa

$$\frac{4.177}{(214)(440)(10^{-3})} + \frac{(1.0)(1.612)}{(355)(5540)(10^{-6})} = 0.864 \leq 1$$

Bolted Connection - The pin location to support the U-Frame

M10 Bolts = Grade 8.8

p_s = 375 MPa

p_{bb} = 1000 MPa Double shear

p_{bs} = 550 MPa threads not in shear plane

Bolt Shear = $\pi \times 5^2 \times 375 \times 2 \times 10^{-3}$ = 59 kN

Bolt Bearing = $3 \times 10 \times 1000 \times 2 \times 10^{-3}$ = 60 kN

Plate Bearing = $3 \times 10 \times 550 \times 2 \times 10^{-3}$ = 33 kN ==> OK

Welding

All welds are 5mm weld all around - no need to check matching electrode (Grade 42)

The Hong Kong Polytechnic University		
Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung	Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

Design Calculations (ABAQUS Model):

A more detailed numerical model of RDP Prototype II was generated with computer programme ABAQUS for the connection design. Fig. 7 shows the ABAQUS model. The numerical model was generated according to the conditions same as SAP2000 model. With the conditions that U-Frame fixed to Base Support with P2 hole and Triangular-Frame fixed at Normal Level. Fig. 8 shows von mises stress of the model.

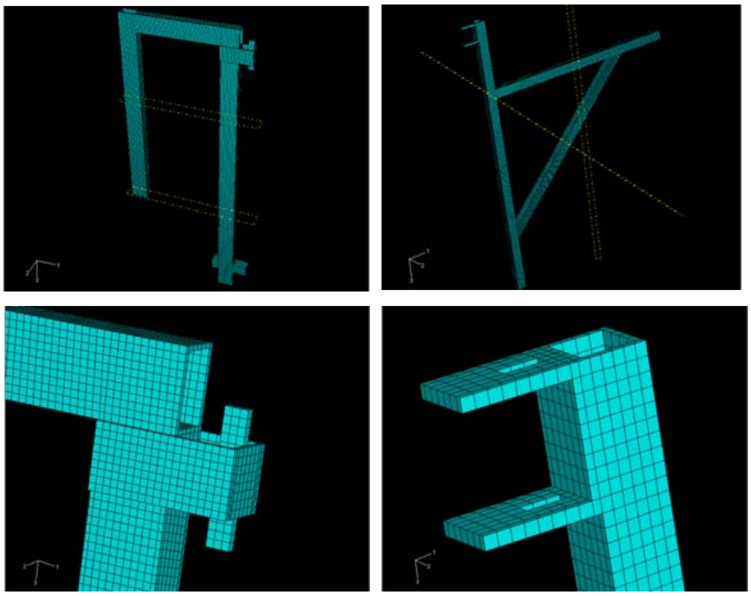

Fig 7. ABAQUS Numerical Model of RDP Prototype II.

	The Hong Kong Polytechnic University		
	Project : Developing a Prototype for a Rapid Demountable Platform (RDP)		
	Calculation for/Subject:	Structural Calculation for RDP Prototype II	
Prepared by: Tracy Chung		Checked by:	Date: 30/8/2007

Ref.	Details	Output/Action

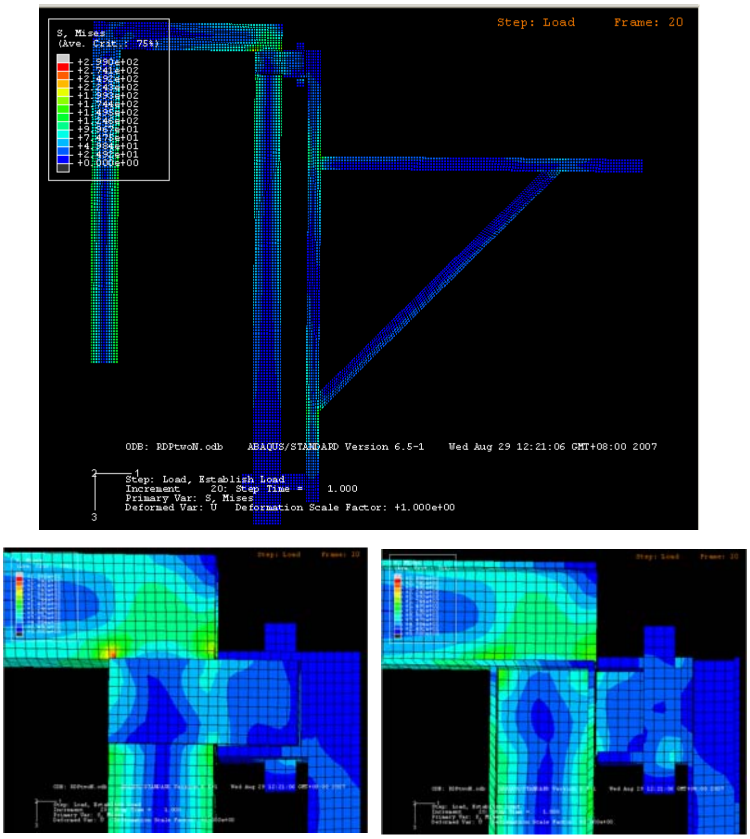

Fig 8. <u>ABAQUS Numerical Results of RDP Prototype II (Von Mises Stress).</u>

<u>ABAQUS results:</u>

Output Case: 1.4DL + 1.6LL Concentrated Imposed Load

From the model

Max. Von Mises Stress	=	220.5 MPa	
	<<	355 MPa	==> OK
Max. Deflection	=	10.655 mm	

~END~