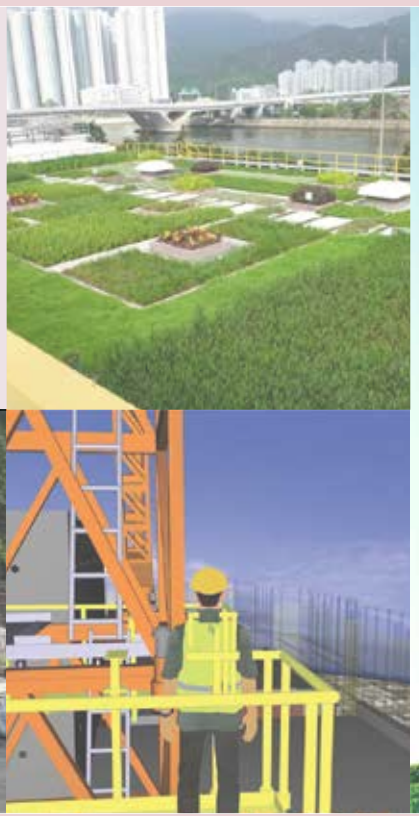
Outcomes of a Collaborative Research Programme with the Construction Industry Part I



MARCH 2015

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

FACULTY OF CONSTRUCTION AND ENVIRONMENT
建設及環境學院

Contents

Foreword

This plain language Executive Summary Report, intended for construction industry leaders, was written particularly to provide a measure of feedback to the industry on the use of its money. Part of the costs of the research programme reported upon here was provided by the Construction Industry Institute-Hong Kong (CII-HK) to The Hong Kong Polytechnic University (PolyU).

Launched in 2009, the CII-HK/PolyU Research Fund was established to support research projects of immediate relevance to industry and, as far as possible, projects with some direct involvement of industry. This latter, applies to 7 of the 11 recently completed projects reported here. The 11 projects represent an expenditure of HK $3.6 million.

The impetus to create the Fund derived from a CII-HK closing down donation of HK $4 million, to which the Faculty added a further HK $4 million. In fact, only HK $1.8 million of the Fund was used for these 11 projects, because the four academic departments of the Faculty themselves contributed half of the costs of each project from their own research budgets. On-going CII-HK/PolyU projects and those yet to be started will be the subject of future reports.

The 11 projects are quite diverse in nature, covering the following five internationally recognised strengths of this Faculty: i.e. advanced structural analysis software systems; fire engineering expertise; advanced construction IT site management systems; satellite based positioning and imaging as related to the construction industry; and, non-technical observations, measurement and modelling of how the construction industry works, analysis of its strengths and weaknesses, as well as how well it fulfills its societal obligations.

I hope this report will play its part in stimulating the industry to continue to work with us. The Faculty itself and the University's Research Institute for Sustainable Urban Development (RISUD) are ever ready to collaborate directly with industry partners whenever possible.

Ir Professor You-Lin Xu
Dean
Faculty of Construction and Environment

March 2015

Introduction to the Research Programme

Background

In 2009, the Faculty of Construction and Land Use (now Faculty of Construction and Environment, FCE) created a Research Fund entitled the 'Construction Industry Institute (Hong Kong)/PolyU Innovation Fund'. The purpose of the Fund was to encourage collaboration in research between the Construction Industry and the Faculty.

The Fund was half provided by Faculty research money and half by a closing down donation from CII-HK, a body which existed to promote university/ industry research collaboration, inspired by the 2001 Construction Industry Review Committee Report's recommendation to that end. On the establishment of the Construction Industry Council (CIC), the role of CII-HK became redundant and its remaining funds were distributed amongst those universities in Hong Kong which undertook construction research. The Hong Kong Polytechnic University received HK $4 million, to which was added a further HK $4 million by FCE, making a total Fund of HK $8 million.

The decision was made that an individual research project could receive a maximum of HK $300,000 from the Fund and that the Fund would allocate no more than HK $1,500,000 per annum until it was finally exhausted. Projects were normally to be of 2 years' duration.

Ir Professor JG Teng

Ir Professor JM Ko

The Research Programme

Because of the lead time in preparing and assessing bids and recruiting project research personnel, 9 of the 11 projects reported here started only in 2012, finishing in 2014. Two of them (projects 4 and 11 below) began in 2009 and were completed some time ago. The Fund's contribution to these 11 projects was HK $1.8 million and the academic departments themselves contributed a further HK $1.8 million.

Five internationally recognised strengths of the Faculty and RISUD are represented in this programme. These include its advanced structural analysis modelling systems, its fire engineering expertise, its leading IT skills in the field of construction virtual reality simulation and its expertise in the business of satellite based remote sensing and imaging as relevant to the construction Industry. The fifth, non-technical and different in kind, is its work in observing, measuring and modelling the state of the industry to understand the strengths and weaknesses of its systems, the issues surrounding the timely supply of land, finance, labour and materials and how the industry (a dangerous one by nature) exercises its duty of care to its workforce.

All of the projects reported below are linked to practical application, a cornerstone policy of HKPU.

The Purpose of this Report

The report is written specifically for construction industry leaders, to feedback on the use made of the money that the construction industry indirectly provided for this programme.

The report is written in plain language, largely devoid of technical terms. Each project is allotted only two pages in providing an outline summary. Appendix 2 gives references to already published papers for follow up in more depth.

Principal Investigators and Brief Project Outcomes

1. Tower Crane Safety Training through Virtual Reality Simulation

Professor Heng Li
Chair Professor
Department of Building & Real Estate

Using the example of the dismantling of a tower crane, a visualization gaming simulation system was created displaying the actions of all workers, as directed by the system users (game players). The research team then developed the system for training purposes. Novices, after training only, tested almost as well as experienced crane dismantlers.

Professor Li is one of the foremost internationally innovative and most cited researchers in the field of virtual prototyping (VP) technologies. His research is strongly rooted in practical construction site application in Hong Kong, ensuring his VP simulation software remains realistic from the user's point of view. His mission is to bring down the costs of project management and site management, through the use of VP as a natural interface assisting decision-making at all stages of the project lifecycle.

2. Improving GPS Accuracy for Construction Surveyors

Dr George Zhi-zhao Liu
Assistant Professor
Department of Land Surveying & Geo-Informatics

A novel method was developed for correcting ionosphere-affected GPS readings in 'real time', with their often unpredictable and varying error sizes. Errors, which can be as much as 100 metres, are reduced to less than 0.5 metres by the technique developed in this project.

Dr Liu is an internationally recognized scientist in the Satellite-based Global Navigation Satellite System (GNSS). Before joining HKPU he worked for 4 years in the Global Navigation Satellite System (GNSS) industries. His research primarily focuses on GPS/GNSS precise positioning and navigation, software development and how GPS accuracy is affected by the atmosphere and the ionosphere. A number of his recent papers published in top GNSS and Geodesy journals were among the top 3 most downloaded papers. He is currently the Director of the International Association of Chinese Professionals in Global Positioning Systems and the Managing Editor of the **Journal of Global Positioning Systems**.

3. Guidelines for Green Roof Systems in Hong Kong

Professor Onyx Wai
Professor
Department of Civil &
Environmental Engineering

The study was built around a 600 sq.m. roof garden in Shatin supported by laboratory work. More understanding was gained on water retention and the run off characteristics of various membranes and soil layers and of the suitability of different plants for roof gardens in Hong Kong.

Professor Wai's research expertise is primarily in the transport and fate of sediment particles in water bodies, including issues of beach erosion and the quantification of sediment-nutrient exchange rates in water columns. He has developed interests latterly in matters of urban eco-greening, eco-roofs, and eco-flood channels for urban areas.

4. Innovative Materials for Soil Nailing

Dr Y.M. Cheng
Associate Professor
Department of Civil &
Environmental Engineering

Soil nails, containing glass fibre reinforced plastic bars, instead of the traditional steel bars, are much lighter and easier to work with during construction. They are nearly as strong as steel and their much greater degree of 'stretchability' makes them a good alternative in better mobilizing resistance to slope movements in the case of looser soils.

Dr Cheng's research interests lie mainly in areas of Geotechnical Engineering, especially in piling, slope engineering and deep excavation, backed by fundamental expertise in discrete element analysis and numerical methods generally. His research is founded upon solid practical industry design and construction experience on such projects as the MTR Island Line, the Eastern Harbour Crossing and the Island Eastern Corridor.

5. Precision in Skyscraper Construction

Dr Yong Xia
Associate Professor
Department of Civil &
Environmental Engineering

During construction of the 118-storey Shanghai Tower, actually constructed levels, floor by floor, were controlled to within 5mm of design levels by performing accurate finite element structural analyses at each floor, taking into account the actual levels of the floor just finished. 30 mm accuracy would normally be considered good practice.

Dr Xia is a specialist in advanced structural analysis, particularly in vibration analysis. He researches in the fields of structural health monitoring, damage detection, big scale finite element modelling and the non-linear vibration of cables.

6. Application of Advanced Structural Analysis to Flexible Rockfall Barriers

Professor S.L. Chan
Chair Professor
Department of Civil & Environmental Engineering

An advanced structural analysis system, able to model structural behaviour in detail even up to the point of collapse, was applied to a flexible rockfall barrier, which had suffered a partial failure. The model was, in fact, able to mimic the actual failure quite closely, suggesting future designs would benefit from prior detailed analysis of this sort.

Professor Chan is very well known for greatly advancing our ability to accurately analyse steel structures right up to the point of collapse. His computer based "simulation design" method has proved itself on several real cases of practical structural steel design since 1998. He was a Principal Consultant to the Hong Kong Buildings Department in the drawing up of the Code of Practice for the 'Structural Uses of Steel, 2011'.

7. An Assessment of the Fire Engineering Approach (FEA) in Building Design

Professor Wan-ki Chow, JP
Chair Professor
Department of Building Services Engineering

Rather than rely on the usual prescriptive rules when designing a building to minimize risk to life through fire, a 'fire engineering approach'(FEA) can take account of the likely behaviour of a fire(s) in the design under consideration. The project was concerned with the CFD modelling of the spread of smoke and fire and providing guidance to the fire authorities on how to judge new design proposals based on an FEA approach.

Professor Chow plays a leading role internationally in research into fire & smoke behaviour modelling in relation to building design configurations. He also plays an important leading role in Hong Kong, alongside the fire safety authorities, in the appropriate introduction of the 'fire engineering approach' to building layouts as a rational alternative to the fire regulations traditional prescriptive layout rules. He has produced over 40 PhD graduates and is the Founding President of the Hong Kong Chapter of the American Society of Fire Protection Engineers.

8. Advanced Instrumentation for Better Understanding of the Behaviour of Soil Nails

Professor Jian-hua Yin
Chair Professor
Department of Civil & Environmental Engineering

Two advanced instrumentation technologies were studied for their potential to obtain more comprehensive information on the actual behaviour of soil nails when resisting slope deformations. The mechanisms by which soil nails work in practice are not yet properly understood in detail.

Professor Yin's research interests include many aspects of geotechnical engineering from the fundamental behaviour of soils, to applications of geo-synthetic reinforcement materials and to applications of the latest advances in instrumentation. He is Vice-President of the International Association for Computer Methods and Advances in Geomechanics and serves on three of its technical sub-committees.

9. Fire Risk Assessment for New Construction Sites

Dr Daniel W.M. Chan
Associate Professor
Department of Building & Real Estate

As a result of this study of fire risk on construction sites, an objective 'instrument' was developed by which the fire risks present on any site can be quantified. This opens up the possibility of comparing the performance of different sites in Hong Kong to establish the current variability and benchmarks and thereby improve the general level of performance over time.

Dr Chan, as a construction project manager by profession, has wide research interests within his field of expertise, ranging from productivity, collaborative contracting and partnering, New Engineering Contract (NEC), PPP, procurement systems and construction site safety. He is an associate professor and since 2013 has been Chairman of the Hong Kong Institute of Project Management's CPD Committee.

10. Measuring the Impact of Prefabrication on the Construction Industry

Professor Geoffrey Q.P. Shen
Chair Professor
Department of Building & Real Estate

A system dynamics based model which links the degree of concrete component prefabrication to the amount of construction waste reduced given various system parameters was developed. These parameters include such as the effects of financial incentives on a project team's 'willingness to prefabricate'.

Professor Shen is a very active researcher who works in close collaboration with industry practitioners on project briefing, planning and procurement activities, always involving the latest appropriate information technologies. Value management is a particular area of expertise for him and he is currently President of the Hong Kong Institute of Value Management.

11. Advanced Structural Analysis for Step by Step Pre-tensioning of Supporting Truss Chords

Professor S.L. Chan
Chair Professor
Department of Civil & Environmental Engineering

To avoid overstraining the sealed joints in a large span glass panelled facade wall, deflections of the slender supporting trusses must be small under strong wind forces. Advanced structural analysis, is capable of dealing with the large deflections that occur during the construction process. This application of advanced analysis proved appropriate in determining the correct truss chord pre-tensioning forces (successively applied to eliminate potential buckling).

Professor Chan is very well known for greatly advancing our ability to accurately analyse steel structures right up to point of collapse. His computer based "simulation design" method has proved itself on several real cases of practical structural steel design since 1998. He was a Principal Consultant to the Hong Kong Buildings Department in the drawing up of the Code of Practice for the 'Structural Uses of Steel, 2011'.

1. Tower Crane Safety Training through Virtual Reality Simulation

Motivation Behind the Study

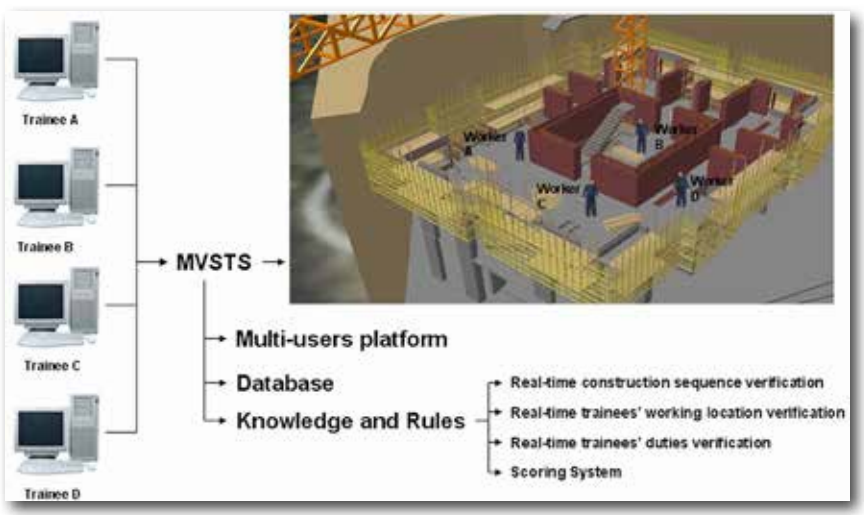
RISUD's virtual reality team in the Building and Real Estate Department, led by Professor Heng Li, has long been developing practical software for visualizing construction operations on site. Realistic 3-D simulations can be made of the handling and placing of materials and components on site. In effect, structures and excavations etc. can be 'built in advance' on the computer screen, with practical difficulties made visually evident, and corrected for, in advance of real construction.

Given the team's expertise, the study was to test whether visualisation software could also be used to create a training tool for safety. The dismantling of a tower crane was chosen as the vehicle. The intention was to graphically simulate each dismantling operation and the movements of the crew in doing so. The system assumes the training of a working team, a 'multi-user' system in the jargon, by placing them in a virtual realistic 3-D crane environment.

Crane dismantling was chosen mainly because tower crane usage is one of the major causes of fatalities on sites in Hong Kong and only 'on-the-job' training is truly effective. 12 accidents, for example, between 1998 and 2005 caused 14 deaths. Over a period of 50 years, there has been more than one crane-related death on average each year. There were 3 crane-related deaths in 2014.

Simulated hands-on experience looks potentially to be a good training approach, and a very useful adjunct to on-the-job experience. Many different practical site situations can be simulated in the computer, and the trainees therefore introduced quickly to a variety of potential situations, 'experiencing' dismantling many times over.

The above argument would only hold if the simulations are indeed realistic in the eyes of trainees. The challenge for this study was the provision of software and hardware that could in fact produce this realistic training environment.



Project Outcomes

Key Features of the System Developed

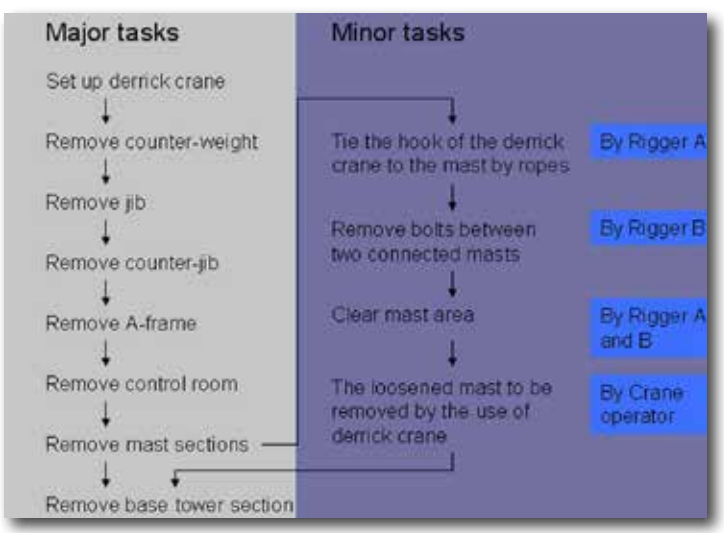
The training system was based on the game engine "3DVIA Virtools", a kit of software routines which enables control of the movements of figures within a 3-D environment and the taking of actions by those figures. The game players (i.e. the trainees) control the movements and actions of those figures which represent themselves. The system 'watches' what the figures do and when, where they go and gives marks by referring to the planned safe actions and movements drill stored in the system. Additional C++ programming was required to create the whole system, alongside the game engine tools and the software for construction of the 3-D site environment.

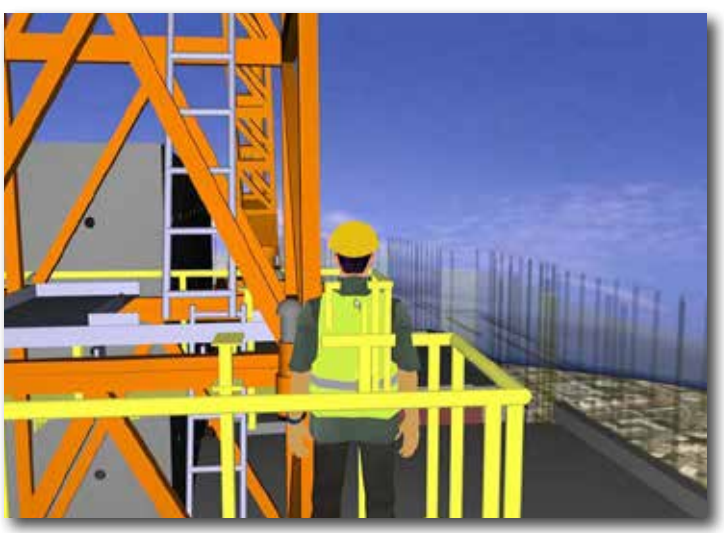
Performances were assessed 1) according to the dismantling sequence adopted; 2) the real-time locations adopted by trainees within the virtual environment; 3) the duties they actually carried out.

The complete dismantling system was divided into 8 major carefully sequenced tasks at the level of removing jibs and setting up a derrick crane. The 7th of these, "Remove Mast Sections", for example, is broken down into 4 minor tasks at the level of fixing hooks and removing bolts. The game player removes a bolt by moving 'himself' to the bolt location with his control device and swings that device to simulate the action of bolt removal. Similarly, other types of action are simulated.

Training Effectiveness

Ten construction workers with no experience of crane work put the system through its paces. Afterwards, a quiz of 30 multiple choice questions on crane dismantling was administered to these 10 novices and to 10 others with an average of 3 years of tower crane site experience. The results were almost identical between the two groups, both scoring at a good 80% level. The novices clearly learned a lot about crane dismantling from this virtual 'hands on' training.





2. Improving GPS Accuracy for Construction Surveyors

Background

Global Positioning System (GPS) technology has an enormous impact on society. Millions of users in Hong Kong take advantage of the smartphone-embedded GPS capability, not to mention the numerous GPS applications by government agencies and professionals, including construction surveyors, land surveyors, and town planners.

Assorted types of error, however, do contaminate GPS satellite signals received by ground GPS receivers, thereby degrading the accuracy of apparent GPS user locations. Among GPS errors, those induced by the ionosphere are the largest. Even under normal ionosphere conditions, the ionosphere-induced error can be as much as several dozen metres and can exceed 100 metres under severe conditions.

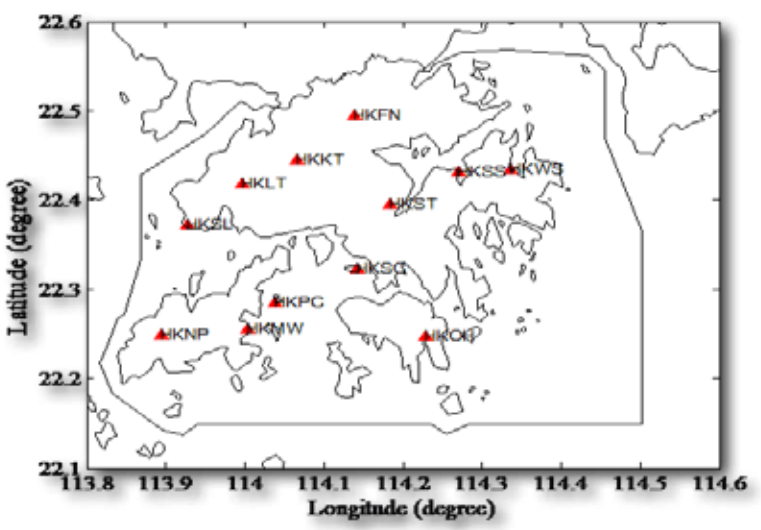
Hong Kong is geographically located at the equatorial ionospheric anomalous region, such that Hong Kong GPS users experience more severe ionospheric errors than users in many other regions of the world.

The research team led by Dr George Zhi-zhao Liu tackled this problem, specifically with the aim of improving accuracy for construction industry GPS users, such as surveyors and town planners.

The Nature of the Problem and the Research Solution

At approximately 60-2000 km above the earth's surface, the ionosphere slows down the satellite signals by varying degrees, since its thickness and intensity are constantly shifting from place to place and minute to minute. This can cause propagation delays and distortions to the satellite carrier wave signals reaching the ground station receivers, including smartphone GPSs which can produce constantly varying positioning solutions. These ionospheric errors also vary randomly in size. In addition, the rapid fluctuations of free electrons in the ionosphere produce a 'scintillating' phenomenon, which degrades a GPS ability to track satellite signals.

Taking advantage of the GPS network of 12 ground receivers spread across Hong Kong, the team worked out how to combine all input GPS signals transmitted to the ground from 30 GPS satellites, 20,000 km high, to develop a precise ionospheric model. This model deduces better GPS user positions by estimating the errors precisely. Their model, the IonHK, improves accuracy to within about 0.5 metres, which is a huge improvement on the 10-30 metres typically attainable otherwise, even under normal, relatively benign, ionospheric conditions.



Geographic Distribution of the Hong Kong SatRef GPS Stations

Project Outcomes

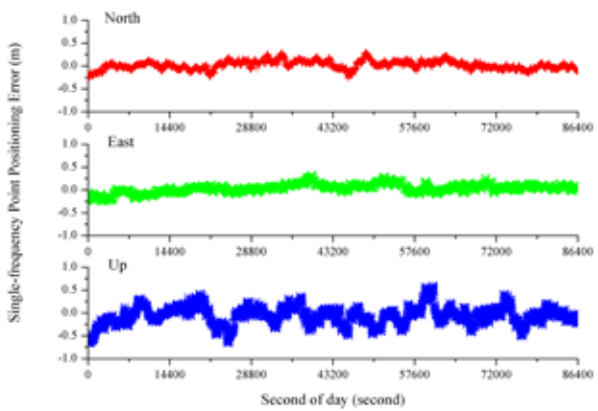
Project Outcomes

The project more specifically:

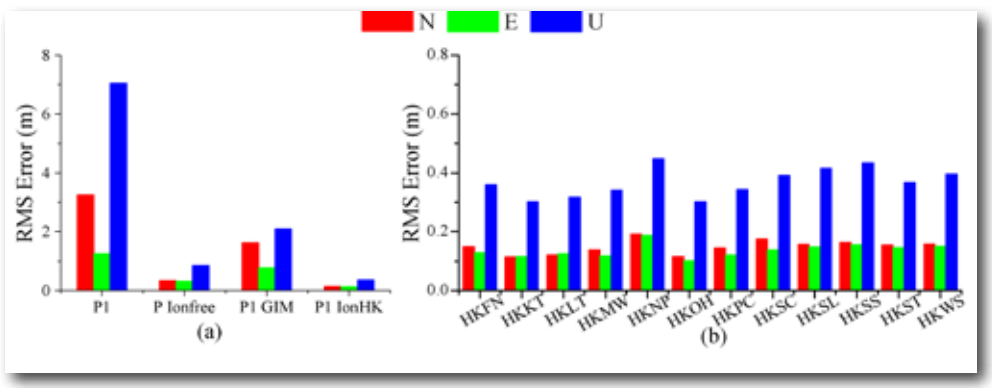
1) developed a real-time ionospheric error correcting model to better serve Hong Kong (and other PRD) GPS users, by making use of GPS data from the Hong Kong Satellite Positioning Reference Station Network (SatRef). The model, IonHK, implemented in computer software, has been in operation since 2013. The approach is entirely novel, in first taking advantage of the GPS Precise Point Positioning technique to resolve ambiguities in GPS carrier phase measurements. It is applicable for modelling ionospheric error in other parts of the world.

2) developed two new algorithms to mitigate the impact of ionosphere scintillation activities on GPS receivers. The algorithms have been fully tested and improve GPS performance even under very strong ionosphere scintillation events.

3) generated a large database of valuable scientific datasets that create a solid foundation to support research and discovery in the future. These datasets include such as ionospheric total electron content (TEC), TEC change rate and spatial TEC gradient. Analysis of these data will help to depict and understand the complex ionospheric variation patterns in Hong Kong and in other world localities.



GPS positioning precision over one day adopting the ionospheric error model "IonHK" (North, East and Up (height) denote three dimensional GPS coordinates)



(a) The GPS 3-D positioning root-mean-squares (RMS) error for four ionospheric modelling strategies. The research team's model "IonHK" has the smallest GPS positioning error.

(b) By adopting the "IonHK" model, the GPS positioning RMS error is smaller than 0.5 metres at all the GPS stations in the Hong Kong SatRef network even though only GPS single frequency pseudorange data are used.

3. Guidelines for Green Roof Systems in Hong Kong

There are several good environmental reasons why roof gardens should be encouraged, especially on new buildings where roofs can be expressly designed to carry their weight. Roof gardens provide personal leisure amenity space, capture carbon dioxide from the atmosphere, mitigate heat Island effects, and by soil filtering reduce the quantities of deposited heavy metals washed away in the storm water drains.

Roof gardens do increase roof loadings, but the effect on structural cost is slight in fact. Roof gardens are necessarily moist, however, and very often wet, requiring special care in preventing roof leakages and avoiding unacceptable maintenance cost. Owners of green roofs interviewed as part of the research, reported that roof leakages do commonly occur, at minor and more significant levels.

Roof gardens usually start with a waterproofing membrane, then a water retaining mat, followed by 25-35 mm. of a proprietary porous drainage layer. On top of the drainage layer is placed soil to a depth of about 8cm to 20cm. Thickness of the vegetation layer may vary from ground cover to about 60cm tall depending on the plant choices.

The study, led by Professor Onyx Wai, was centred on a 600 sq.m. green roof installed on a two-storey building in Sha Tin. The university's laboratory provided essential backup in studying the relationship between different green roof systems and storm water runoff mitigation. The study included a literature review, field measurement, laboratory experiments, numerical modelling, and interviews with owners of green roofs.

Findings and Understandings Gained

A 5mm thick cotton mat worked well at Sha Tin as both a protection to the waterproofing membrane during construction of the roof garden and as a moisture retention layer. From 2014, the use of asbestos containing mineral wool moisture retention layers, which was previously popular, is no longer allowed.

Laboratory experiments have demonstrated the amounts of rainwater retained by soil. For rain at 10mm/hr, 53.9% is retained by the soil for the benefit of the plants and only 46.1% is drained off. At 30mm/hr, the figure retained is 31.9% still a useful amount. Given that 92% of all Hong Kong rainfall is at 30mm/hr or less, this explains why roof gardens do well.

There are no universal standard guidelines for waterproofing but the advice of the research team is to AVOID the traditional and inexpensive bitumen/ asphalt and use a thermoplastic material such as PVC instead and to apply two layers. Such 'double-ply' solutions are common overseas. Thorough testing for water leaks is then necessary. Flooding tests, supported by intra red thermal imaging and moisture sensor tests, are all useful in this regard and recommended by the team.

Sha Tin Experimental Green Roof

Project Outcomes

Suitable Planting

It is found from the ShaTin experimental trials and interviews that some plants are undesirable and some very effective. The effective plants can 1) provide even and dense cover for years 2) can compete with and prevent colonization by weeds 3) can be inexpensively maintained by only mowing and pruning. The undesirable plants, by contrast cannot provide good coverage, 2) do not compete well with weeds 3) require labour intensive care, particularly in weeding.

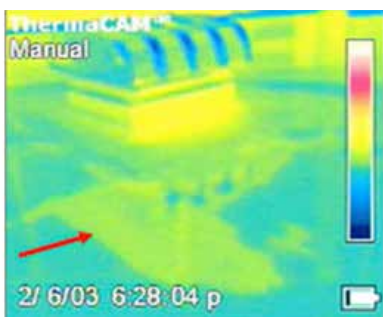
Plants such as **Zoysia** spp, **Axonopus Expressus, Nephrolepis Exultata, Asparagus Cochinchinensis, Forsythia Suspense, Duranta** spp are effective.

The plants to be avoided are Sedums, **Arachis Duranensis, Arachus Pintoi, Alternanthera Payonychioides** and **Rhoeo Discolor.**

Team View

Since green roofs are practical propositions, there is every reason to include roof-greening as a normal provision in new buildings in Hong Kong. Not only do they bring useful environmental benefits, but also additional open space that is much needed in Hong Kong urban areas. Roof-top designs will probably also develop to take advantage of the vegetation possibilities.

Flood Testing



Thermal Imaging

Moisture Sensor Measurement

4. Innovative Materials for Soil Nailing

Background

The stabilization of slopes has been an ongoing programme of activity in Hong Kong ever since the 1972 landslide disasters that caused 138 deaths. The soil nailing technique is often employed, unless circumstances dictate a more expensive retaining wall. An array of soil nails at 1.5 to 2.0 metre spacings are placed in holes drilled 15 to 20 metres into the slope at a downward angle of about 15 degrees. The drilled holes are then filled with grout, either under simple gravity or under some pressure (rarely). Soil nails are usually made of high tensile steel.

Soil nailing, however, is less effective with loose or clayey soils and how to best make use of pressure grouting to improve this situation is an ongoing topic of research led by Dr Y.M. Cheng. That research also involves study of the comparative effectiveness of conventional steel soil nails and fibre reinforced plastic (FRP) nails, specifically glass fibre (GFRP) and carbon fibre (CFRP).

The new materials have been explored because they can be as strong as, or stronger than steel, and are much lighter and easier to work with on slopes difficult to access. They are also less subject to corrosion. On the other hand, they are not as stiff as steel nails and must extend further to mobilise soil resistance when the slope starts to slip.

To work effectively, a good bond is required between the soil nail and its surrounding grout as well as a good friction grip between the grout 'column' and the surrounding soil being stabilized.

The research was based on laboratory soil nail pull out tests and field tests in Hong Kong, Korea and Australia, backed up also by numerical simulations using the software system FLAC3D. The Korean and Australian collaborators were separately funded.

The Findings

The ideal soil nail would be light, strong, bond well with grout, would not corrode, is cheap and easy to handle, cut, and join. No material can meet all these needs.

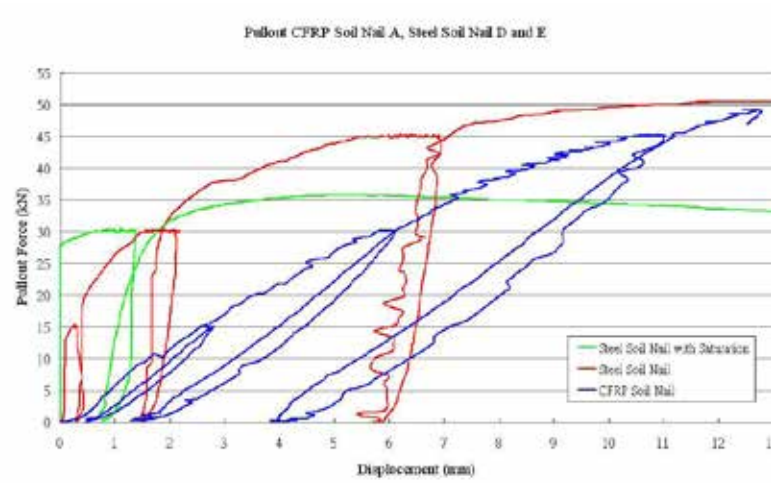
The study results show that GFRP bar is just a little less strong than steel, but CFRP can be two to four times stronger. Since CFRP only stretches half as far as steel does before breaking, the great strength of CFRP is not useful. Its much greater cost, therefore, effectively rules it out for practical use.

The elastic modulus for a GFRP bar is only one fifth that of a steel bar and therefore stretches considerably more than the steel bar for the same elastic range force. Ease of handling, however, a good enough strength and a reasonable cost, gives GFRP a place when its 'stretchability' would be beneficial in mobilising soil shear strength in the case of looser soils. A slightly higher factor of safety should be applied, but more research on creep effects is needed to determine how much. One important finding by the team is that expansive grout increases efficiency by up to 50%, based on pull out tests, because of the tighter grip and higher bond strength.

Project Outcomes

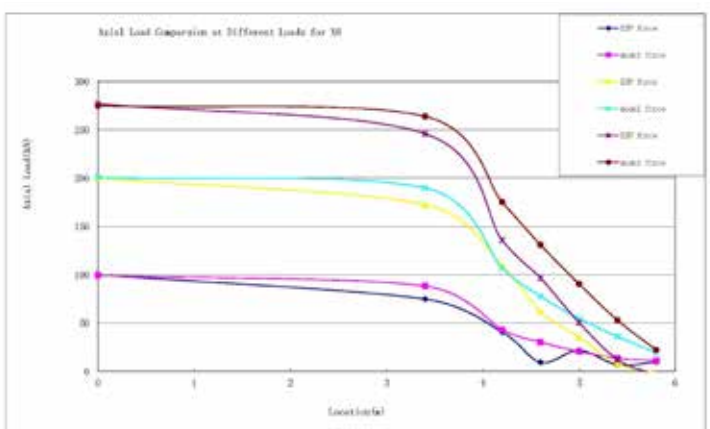
The research revealed new information on the distribution of bond stress along the nail. In the field it is found that GPRP bars are bonded to the grout for greater lengths than steel bars, suggesting more robustness over the long term as more of the bar is carrying load. Steel bars tend to sustain high bond stresses over relatively short distances before they reduce quite quickly.

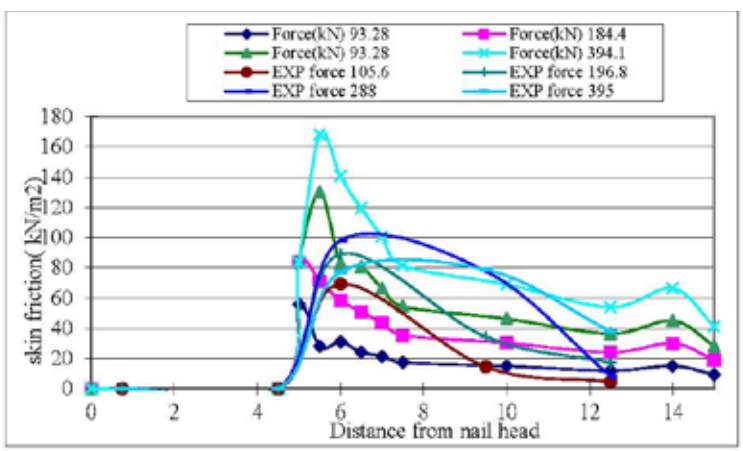
A final observation by the team is that the simulation software FLAC3D model gives results comparable to experimental values, which helps to lower the costs of research yet to be done.



Recommendation

The long term behaviour of soil nails has not been much studied. Creep will lower nail efficiency over time, and we also need to explore long term debonding between bar and grout (if any) and how grip between the grout column and surrounding soil changes over time.





5. Precision in Skyscraper Construction

Background

It is important that all buildings are built to precise dimensions to avoid undesirable internal stresses so that pipework and fittings are easily assembled while taking account of settlement effects and varying ambient temperature effects as construction proceeds. For supertall buildings, however, because loads are so huge and there are so many members, built dimensional accuracy is both harder to achieve and yet is doubly important that it be achieved.

This project, run by Dr Yong Xia, was concerned with a 118-storey Shanghai Tower, built of mega frames supporting the floors placed around concrete core walls and columns. It is not easy to assemble a large number of steel pieces and concrete elements to be exactly in the right place storey by storey. The project consisted of an 'on-the-job' research study of a superior procedure for ensuring construction accuracy. The procedure involves floor by floor Finite Element analysis integrated with a Kalman filter algorithm to remove measurement errors and dimensional temperature effects known as 'noise' in the jargon.

The Traditional and Trial New Procedure

The traditional procedure is one of successive floor by floor correction as follows:

1) Measure the levels at various points on finished floor X; 2) compare these figures with the required design figures; 3) adjust structural wall and column heights for the next storey to compensate, in the light of experience from previous floors; 4) construct the next storey. Then measure the levels on floor X+1 and repeat.

The research project procedure being studied was intended to improve this compensation process for closer continuing control of accuracy as construction proceeds.

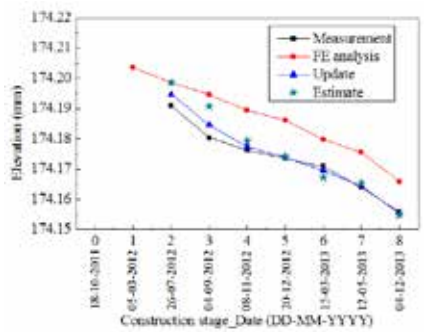
The procedure was to 1) measure the levels on finished floor X; 2) do a full finite element analysis of the whole building as if floor X+1 had been constructed, also making use of that step 1 measured data, to get an initial estimate of the X+1 floor mean level; 3) refine/ update the calculated step 2 levels using the Kalman algorithm to filter out the effects of inherent measurement errors and environmental ambient temperature effects and ; 4)measure the X+1 mean floor level after storey construction and repeat the procedure for floor X+2.

The Results

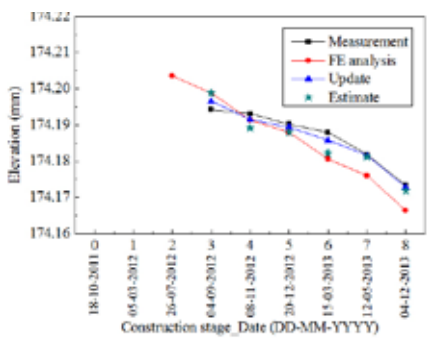
The conclusions of the study are that floor by floor actually constructed levels were closer to design values by the order roughly of 5 mm.

Some numbers are of general interest for such a major structure. The core wall settled about 60 mm evenly over the 21 months from July 2011 to April 2013. The super outer ring of columns settled rather less at about 35 mm in the best case and 45 mm in the worst. The latter settlements proceeded at the same rate, however, for most of the period so no difficulties were encountered on that score because of the difference.

As to the differences between actual measurements, the finite element calculations and the 'noise' filtered improved estimates of levels, the graphs for floor 37 show the comparative figures for the period mid-2012 to end of 2013. The estimates are less than 5mm different from the actual measurements for both the core wall and super columns indicating the effectiveness of the proposed technique in predicting floor levels during construction. More importantly, this means that the research team's procedure can control the construction mean floor levels to within 5mm of design levels. The traditional method is not likely to be that good. A figure of 30mm is the criterion given in the Chinese code JGJ 3-2002.

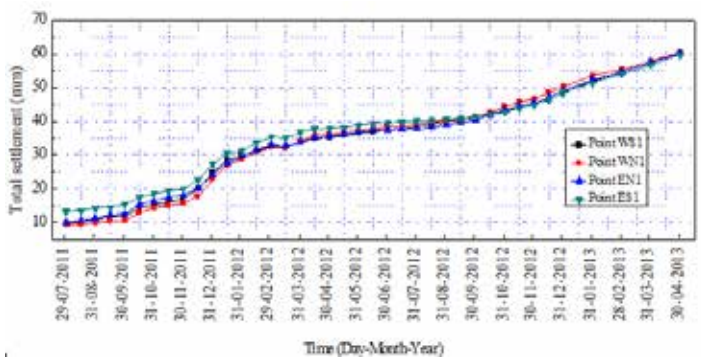


a) Core Wall

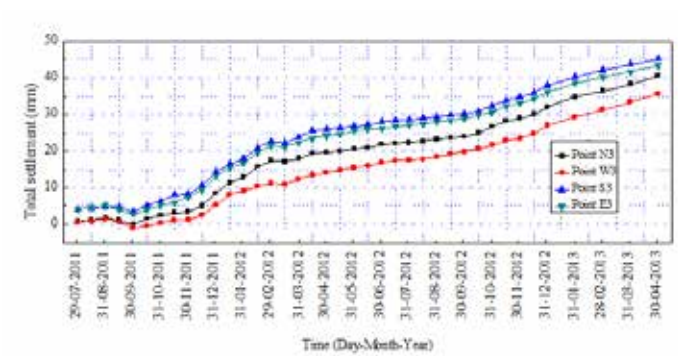


b) Columns

Elevations of 37th Floor by Date



Foundation Settlement of Core Walls



Foundation Settlement of Super Columns

6. Application of Advanced Structural Analysis to Flexible Rockfall Barriers

Background

The project was led by Professor S.L. Chan, who has developed advanced structural steel analysis software capable of accurately modelling the nonlinear behaviour of a structure up to final collapse. His well-known NIDA software models post buckling member behaviour and takes full account of the large deformations which occur once a structure moves into the range of plastic deformations.

In Hong Kong, to protect against potential landslides, flexible barriers are sometimes strategically placed to catch the debris. In June 2008, in the Jordan Valley, structural failure occurred before the net was damaged, of two vertical 140 mm square posts, of hollow cross section and 4mm wall thickness. These were 5m high, stayed by cables and set in shallow concrete block foundations. There were 15 of these posts at 10m intervals supporting steel mesh netting rather in the manner of a tennis court net.

The post foundation blocks were moved a couple of metres down the slope by the debris (but the mesh held, retaining the debris). The one post directly hit by the debris was bent very sharply just above the foundation, with its top lying well uphill of the foundation's new location. The second post was only slightly bent.

A structural failure represents an opportunity to learn how to do better in the future. Only software such as NIDA is capable of exploring bahviour right up to collapse. NIDA was modified to take account of the flexible netting and cabling resulting in NIDA-MNN, (Nonlinear Integrated Design and Analysis with Moving Mode Net modelling). This required an original contribution to the art of structural finite element modelling. A new type of element 'connection' allows one element to slide over another.

Limitations of Analysis

The loading on the barrier was estimated as a uniformly distributed pressure (UDP). The mass of the 110 cubic metres of material retained by the barrier could be estimated but impact force relates also to slip velocity, which was unknown. Analyses were accordingly made with different assumptions of debris velocity. Some guidance was available from the fact that the barrier did succeed in performing within its targeted energy absorption capacity.

The posts were assumed pinned, i.e. the foundation blocks could easily rotate. NIDA-MNN was not able to model block sliding rigid body failure, but if structural failure were to occur before any sliding of the foundation blocks, the analysis would be appropriate. If failure was initiated by foundation sliding, the model outputs would be compromised and approximate only.

Landslide Scar

Project Outcomes

Analysis Findings

The NIDA-MNN results, for a UDP of 50 kPa, show that both post failures could have been caused by a combination of bending and column axial compression. The bending in one case was due to the weight of the debris and in the other by the debris-induced pull on the netting attached to the post. The compression loads are due to the forces in the stay cables running from the tops of the posts to uphill and lateral anchorages.

The shear forces in the posts were found to be within designed capacity and the calculated post and netting deformations were in line with those observed. The foundation reactions, at 350-450 kN, were probably big enough to have caused sliding of the shallow foundations, adversely affecting the realism of the model and the precision of its calculations though not the interpretation of the results in general terms.

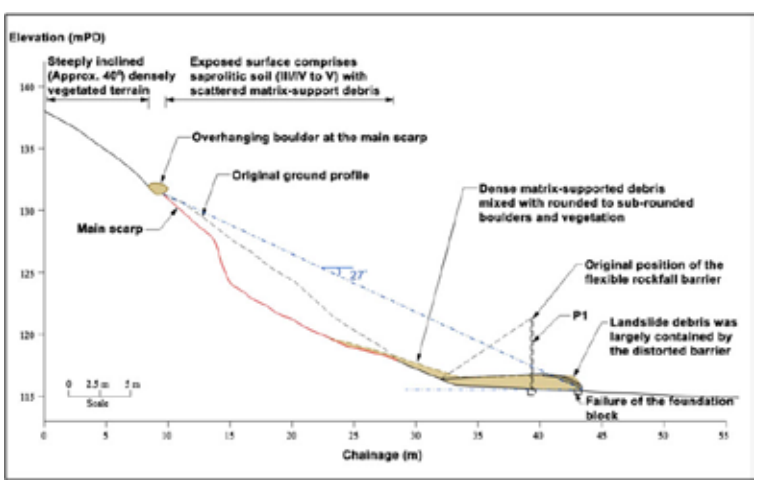
Since observed deformations fitted those calculated in general, a back analysis of the strain energy stored in the various elements and in the deformations of netting and posts produced a total of 280kJ, representing 61% of the designed energy capacity. There would be some additional friction losses that are not calculable, but the barrier did indeed succeed in holding the debris, giving further confidence in the NIDA-MNN model.

Lessons Learnt

The study demonstrated that advanced structural analysis (i.e. Deformations analysed up to failure) can be applied to structures containing flexible cable and steel netting items. NIDA-MNN reproduced the post failures modes observed in practice. Actual deformations were of the same order as those calculated.

As for the design of flexible barriers, although the barrier held, attention is needed on foundation fixing and on steel post design to take compression loads as well as bending loads. The fact that the energy dissipation features failed to activate requires attention to detailing.

Barrier holding back much of the debris



7. An Assessment of the Fire Engineering Approach (FEA) in Building Design

Background

The performance based approach to the design of buildings against fire has been allowed, for over 10 years, by the authorities in Hong Kong and other places. Performance based design, or FEA, is an alternative option to the compliance of long laid down prescriptive rules. The FEA takes a proposed building layout design and its likely contents, and determines the nature and spread of potential fire breakouts, both smoke and temperatures effects, and the performance of escape routes. Computer modelling of both fire and escape behaviour is the means by which these determinations are usually made. The model outputs, of course, must provide convincing representations of the fire realities in any particular case, if the standard prescriptive rules are to be set aside.

The research team, led by Professor Wan-ki Chow, has studied computer fire behaviour modelling for 20 years. Three dimensional behaviour computational fluid dynamics (CFD) models, for compressible fluids (which smoke and gases are), have now become capable of modelling fires in buildings of realistic sizes.

Nevertheless, however powerful the analysis, the software is of no use without valid inputs of heat release rates (HRR) for all flammable materials in the building when burning and the quantities and densities of smoke and gases generated. Internationally recognised software that simulates heat release rates, such as the Fire Dynamics Simulator (FDS) is available, which can be directly coupled with a CFD system. FDS, too, needs valid input data.

The research team, for years, has been involved in HRR experimental research and made much use of full scale burning facilities in China, which are essential for validating HRR lab work and FDS and CFD model outputs.

The Project Objectives

A) Simulation results of solid fuel combustion have led to arguments and debates to the detriment of the application of the FEA. The results of full scale burning tests of some solid fuels were therefore compared with FDS predictions.
B) To report to the HK fire authorities on weaknesses in CFD analyses, and guide them in the assessment of CFD outputs put forward under the FEA for approval, can be safely relied upon.

Project Outcomes

Full scale burning experiments were made with different chipboards and a PMMA plastic. Basic data for the record were obtained and, importantly, the FDS predicted HRR curve shapes and magnitudes agreed well with the experimental data. The team learnt to err towards providing extra computational space for assured accuracy and that extending the space vertically was more useful than extending horizontally. Doing so, for instance, ensured a more realistic simulation of the ‘spill plume’ through the door opening of the physical experiment. Not unexpected, was that HRR strongly depends on moisture content, as much heat is removed from the fire because of the latent heat demand of evaporating moisture. Accurate FDS outputs are very sensitive to the correct material parameters, which mean that for any FEA based approval application, care must be taken to ensure that CFD simulations are supported by a thorough understanding, through burning tests, of any new materials expected to be in the building.

Project Outcomes

As to the second purpose, a list of recommendations was derived for the Fire Authority, on the checks to be made of the submitted fire performance calculations. These include the turbulence parameters used, model boundary conditions, simulations 'grid sizes' and pressure distributions. Back-up experiments on scale models are highly desirable in engendering confidence in the calculations.

Difficulties in CFD modelling include the modelling of the instability phenomena seen in reality, and the uncertainty in modelling the turbulent exchange flow across openings in walls.

A final comment might be made. CFD modelling of fire behaviour is still far from a precise science. But this does not mean that the FEA route is a dubious one to take, because at least an approximate picture of what may happen is being made for the particular geometry of the intended building. There is nothing scientific about the alternative approach, whereby simple prescriptive rules are laid down about such as corridor widths and the partitioning off of shops in open mall areas. Fire behaviour prediction, already useful in several respects, will become gradually more precise through continued research in the future. In fact, prediction of the spread and intensity of smoke can be described as good, which is of great significance because often it is the smoke inhalation which kills.

Full Scale Fire Burning Test for Heat Release Rate

8. Advanced Instrumentation for Better Understanding of the Behaviour of Soil Nails

Background

As stated in the '**Innovative Materials for Soil Nailing**' report, soil nailing is commonly applied in Hong Kong as part of the Government's long term programme of stabilizing potentially dangerous slopes. Soil nailing provides an economical solution, when retaining wall solutions are not essential.

Experience has shown that soil nailing, essentially a pragmatic approach, works in practice as long as established design rules are followed. Soil nails are a passive form of reinforcement, providing resistance through friction and bond to soil movements down the slope, limiting that movement in the process, and putting the nail into some tension in reaction to the limited movement.

Soil nails run 15 -20 metres into the slope inclined downwards at 15-20 degrees, normally forming part of an array at 1.5-2.0 metre centres. Almost always, in Hong Kong, the nails have been heavy high tensile steel bars surrounded by grout forming an inclined 'column' with a steel bar down the centre. There is some interest now, however, in the adoption of glass fibre reinforced plastic bars (GFRP) in place of steel in some situations (see report above '**Innovative Materials for Soil Nailing**').

Insufficient Soil Nailing Fundamental Research

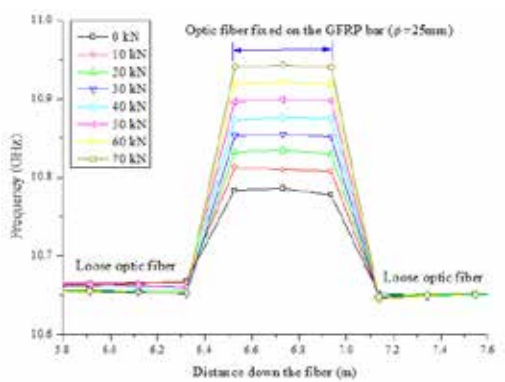
In spite of much effort by many researchers, only a limited understanding exists of the fundamental interactions occurring between soil and nail, such as the extent to which the whole length of the soil nail is employed in resisting soil motion. The evidence suggests that a relatively short length of a steel nail provides the resisting force, wasting the potential of the rest of the nail. Improved design can only derive from accurate knowledge and understanding of the actual mechanisms.

The lack of fundamental understanding arises because it is difficult to measure the stresses and strains in real soil nails. Field research is expensive and disruptive to site progress: the various gauges are electrically powered, and short circuits are frequent. The cheaper laboratory pull out tests are useful for testing bond/ friction properties between nail and the surrounding medium, but the type of loading is not the same as that applying to a passive soil nail within a real slope.

Purpose of the Project

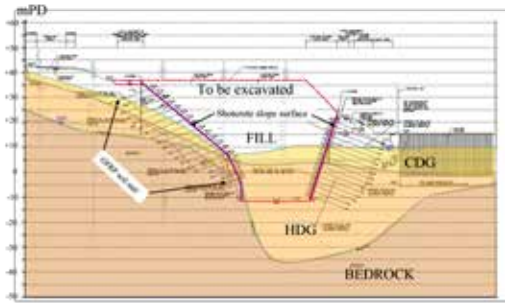
Fibre optic sensing technologies, replacing electricity with light, are now available. The accuracy can also be greater (at 0.0001%) and the prospect of clamping an optical fibre along the full length of a soil nail and detecting movement at any point is attractive. Electrical strain gauges must be spaced at intervals and preparation and glueing to the nail is much more time consuming.

The project, run by Professor Jian-hua Yin, explored the potential for two technologies: 1) Brillouin Optic Time Domain Analysis (BOTDA) sensing and 2) Fibre Bragg Grating (FBG) sensing .

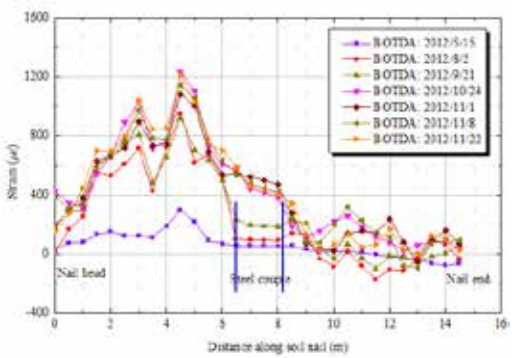


BOTDA Calibration Results

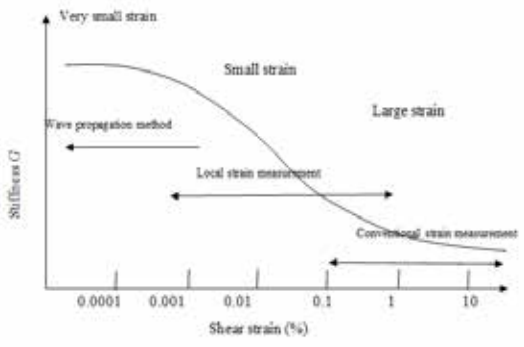
Project Outcomes



The Ho Man Tin Excavation



Strain-as Distributed Along Soil Nail



Notional Stiffness versus Shear Strain Model

BOTDA sensing is based on back scattered light generated at different positions along the length of the fibre. The back scattering is related to the strain and temperature change at that point. The cable must be slightly pre-tensioned so that lengthening and shortening strains are both detected.

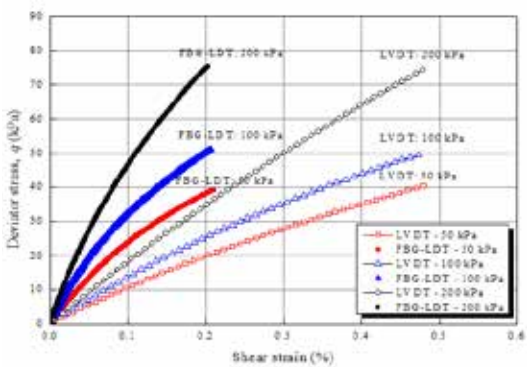
The FBG is a very small point device placed at intervals along an optical fibre. Some of the light travelling along the fibre is reflected at the FBG at a particular wavelength depending on the grating. Temperature and strain changes at the grating location change the wavelength of the reflected light.

Experimental Findings Relating to BOTDA and FBG Based Sensors

BOTDA sensors were laboratory calibrated before installation on a 16m GFRP soil nail site in Ho Man Tin. The fibre was clamped to the bar at 2m intervals. The system successfully measured the distribution of strain along the bar, indicating how it changed in magnitude.

FBG sensors could only be tested on laboratory pull out tests within the funding limits. On GFRP pullout specimens, the strains exhibited the expected 'hysteretic' pattern when the load was applied in cycles of ever growing maximum load.

Of particular interest were tests at 'small strain' levels, only practicable with the precision and accuracy of FBG sensing. Relevant to the design of foundations are the higher levels of stiffness a soil theoretically possesses at small shear strains. The team has shown that an FBG allied with a local displacement transducer (LDT) can reliably reproduce strain/ load graphs in the 'small strain' region between 0.001% and 0.1%. The extra available stiffness revealed at this level of strain is not allowed for in design, because instrumentation to date has not been able to measure it. The research raises the prospect of more economical designs in future.



New FBG Instrument Performance versus Traditional LVDT Instrument

9. Fire Risk Assessment for New Construction Sites

Background

Fires occur regularly on building construction sites. In Hong Kong there were 4 in 2013, for example, and as many as 11 in 2011. 24 were recorded in 2001.

To help in this situation, the research team led by Dr Daniel W.M. Chan has made a detailed study of the causes of site fires, tapped into the abundant knowledge and 'hands-on' experience of hundreds of construction professionals and produced a fire risk assessment 'score' procedure which can be used on any new site before the start of work. Conscientious use of the procedure will enable weaknesses in the precautions in place against fire to be identified in advance. It is believed the work is innovative, in that no evidence of similar work, and no similar provision to help contractors, has been found by the research team in the literature.

The Research Objectives and Process

The aim was to establish a comprehensive and practical fire risk assessment 'tool' for new construction sites.

The formal objectives were

1) To identify the key construction site fire risk factors (eg. 'electricity management') and sub-factors to the key factors (eg 'use of earth leakage circuit breakers')
2) To develop a fire risk assessment model of weighted risk factors and sub-factors for use in measuring and comparing the overall risk levels of different sites
3) To enable a site manager to identify high fire risk situations and take early remedial action.

A comprehensive list of fire risk factors and their associated sub-factors was put together after an extensive literature review, many meetings and interviews with project managers, safety managers, safety officers, fire safety engineers, government officers and others. 11 key risk factors were identified and 48 sub-factors spread across them.

This was followed by an allocation of 'importance' weightings to all sub factors, giving key factor weightings as the sum of their respective sub factor weightings. Importance, in this context, is defined likelihood of causing a fire. Weightings were determined using a five-point Likert scale from 'least important' to 'most important'.

Data from 46 safety and project management personnel, derived from meetings and formal surveys, were then subjected to statistical testing, resulting in the elimination of key factors and sub-factors which contributed to fire risk in only a very minor way. The simplified and more practical list comprised 9 key factors and 20 sub-factors.

The final analysis was to assess the degree of risk associated with each sub factor. 149 experienced and targeted practitioners, also with awareness of previous fatalities in Hong Kong, then allocated risk in terms of 'level of severity' on the one hand and 'likelihood of occurrence' on the other, using Likert scales. A risk score for each subfactor and key factor was produced as a function of the likelihood of occurrence and its level of severity. Finally, a composite overall fire risk index was computed, representative of Hong Kong, which can serve as a preliminary benchmark for reference within the construction industry.

The Findings and Outcomes

The 9 most important key factors in order of highest risk index are:

1) Law enforcement and on-site supervision
2) Storage of flammable liquids and dangerous goods
3) Attitude of main contractor towards fire safety
4) Fire service equipment and installations
5) Means of escape in case of fire
6) Means of access for firefighting and rescue purposes
7) Electricity management
8) Safe site evacuation procedure in place
9) Safe behaviour of on-site staff

The list of key factors and sub-factors can be used with confidence on any new site as a thoroughly researched checklist. An independent fire expert can examine a site's safety level provision against fire for all factors and score each on a '5' for excellent provision and a'1 'for totally inadequate provision. The developed model can be used as an objective instrument for measuring and comparing fire risk levels at different construction sites and identifying high risk areas. This is a good basis for a new study, in fact, comparing many sites to provide a solid benchmark of current levels of fire risk-taking in Hong Kong, the results of which could lead to higher standards over time.

The research methodology would be applicable in many other parts of the world, not only in Hong Kong, enabling international comparisons to be made.

Source: Wen Wei Po 文匯報

10. Measuring the Impact of Prefabrication on the Construction Industry

Background

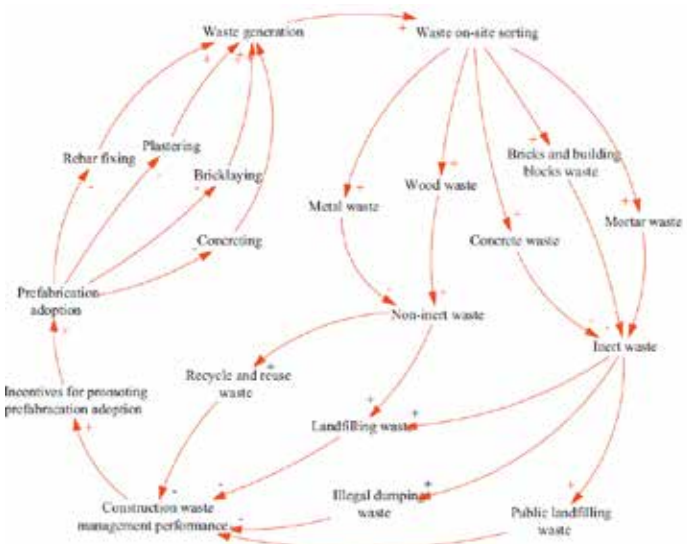
There has long been a need to reduce the volume of wastes produced by the construction industry, which is filling up the landfills and wasting the opportunity to recycle the materials available after building and infrastructure demolition. The prefabrication of concrete structural components in factories makes for less waste in the first place (various case studies show reductions of the order of 50% to 80 %). More demolition concrete is recycled if it consists of prefabricated units rather than concrete originally cast in situ.

Nevertheless, it seems to be the case that buildings concreted in situ are cheaper to build than prefabricated ones, albeit the latter enables faster production and construction times, and more assurance of the concrete's quality. In general, but not of course in all cases, developers and contractors respond more to financial imperatives than to environmental ones such as waste reduction, which is the focus of this project.

The study was concerned with how to quantitatively assess the contribution of prefabrication to waste reduction and the provision of a means to simulate alternative policies. As examples, the effects on waste reduction of two Chinese operational financial subsidy/incentive policies were explored.

System Dynamics Model

The principal output of the project is the development of a model of wide applicability, both as an aid to understanding and as a tool for the quantitative estimation of waste for proposed new building cases. Led by Professor Geoffrey Qiping Shen, the team recognized that it was essential to understand fully the nature of the causes and effects of the types and quantities of waste from all activities involved from the start of prefabrication to their being deposited in landfills. In addition, since the entire system comprises a dynamic cyclical cause and effect 'flow network', the well-known System Dynamics approach was adopted as the core approach to the whole system model. Variables influencing material flows were identified and their relationships and the 'interaction effects' underlying the identified variables were also depicted in the causal loop diagram.



A separate 'stock flow' model applied to the prefabrication process was developed based on the qualitative network model above, to allow calculations of waste-related parameters and other resources to be used under predefined scenarios, with the expectation that the best policy mix can be identified prior to production.

The model will be widely applicable, though of course it is not possible to represent all possible scenarios. The existing model then becomes a prototype for 'customizing' to fit the application situation.

The model was validated and calibrated using data from a building in Shenzhen.

Scenario Analysis

As examples of scenario analyses, the model was used in simulation mode to separately compare two existing Chinese approaches to subsidy policy intended to encourage prefabrication and then to examine the effects of applying both policies simultaneously. Simulations were run for 22 months.

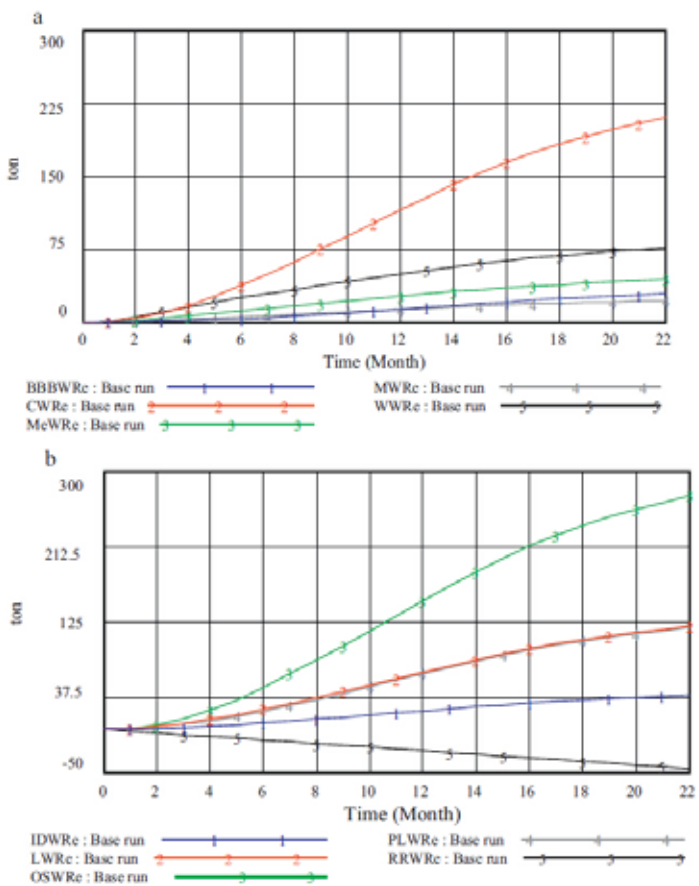
The first policy approach, SPESA, provides subsidy for each square metre of building plan area where prefabrication occurs. The second, ITB, was to provide Income Tax Benefit.

A baseline setting of the simulation produced a 'willingness to prefabricate'(WAP) score of 5.56 and an achieved waste reduction quantity (TCWR) of 17.76 tons.

SPESA changed behaviour such that WAP increased to 8.91 and TCWR to 63.13 tons when the subsidy was set at 60 yuan/sq.m. A 40 yuan/sq.m subsidy gave 7.43 and 27.9 t respectively. In the case of ITB, a 30% tax benefit reduction produced values for WAP and TCWR of 6.08 and 19.72, only a marginal improvement and virtually identical to the case when ITB was at 15%.

When both SPESA and ITB were applied simultaneously, at the higher levels of subsidy, WAP increased to 10.25 and TCWR to 66.25 tons.

The positive effect on Willingness to Prefabricate is clear for SPESA, and very small for ITB. When both incentives applied, however, WAP increased even further than with SPESA alone. The effect on total waste reduction is slightly amplified when both incentives apply.



11. Advanced Structural Analysis for Step by Step Pre-tensioning of Supporting Truss Chords

Background

The design of a completed structure might be a sound one and safe. During construction, however, the loadings and member fixities, different from those of the finished structure design loadings, might well produce unsafe conditions at the time. Temporary supporting works might be difficult and expensive and it can sometimes be economical overall for the designer to also allow for loads experienced during the construction sequences. With the fast structural analysis simulation capability of the research team's software system, NIDA, a comprehensive exact analysis appropriate at different stages of construction has become a practical possibility.

This study led by Professor S.L. Chan required nonlinear analysis of pretensioned trusses supporting a glass wall facade. The need for sequential analyses, in this case, arose from the fact that different chord tensions had to be applied by jacking at different stages. The problem arises when any particular chord rod is tensioned, a consequential change in tension occurs in other rods already tensioned.

The Structural Problem and Procedure adopted

A glass facade is subject to lateral wind forces causing sideways bending of the facade supporting trusses and the possibility of buckling in truss chords which bend into compression. Either heavier trusses can be adopted, which usually defeats the architectural objective in the case of glass facades, or the truss chords can be pretensioned. Getting pretensioning right is complex, because the small member extensions needed to achieve the correct forces are quite significantly affected even by changes in ambient temperature as well as by the subsequent pretensioning of other truss chords in what is a 'joined up' integral structure. Even creep in steel is a relevant factor and foundation settlement. The ultimate aim is a facade which can withstand high winds and the full range of ambient temperatures, while deflections remain sufficiently small that sealed joints are not overstrained and no leakage occurs.

The NIDA software is particularly precise and was found to be suitable in the event. Apart from temperature and creep, NIDA takes full account of the changes in geometry of a slender structure when calculating bending moments, for example, and can simulate the effects of loads acting ever so slightly off line due to the 'imperfections' of real mechanical joints.

The support trusses concerned spanned 14.68 m and were 14.23 m wide.

The complete structure was first analysed with all pretensioning at the design levels. The values of pretension force to be placed in each chord initially was deduced by removing member forces one by one in reverse tensioning order and doing a complete analysis, i.e. a reverse sequential analysis each time.

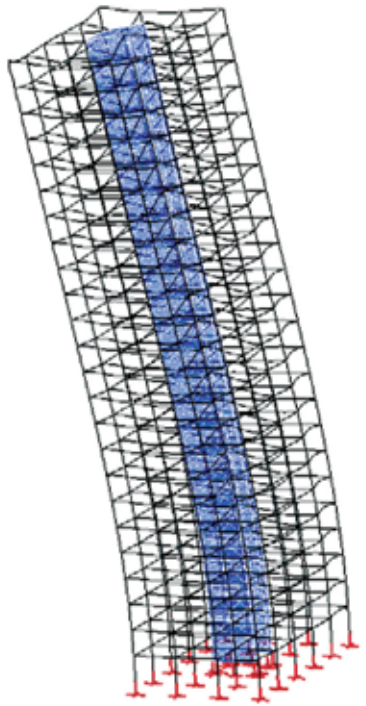
A simulated experimental NIDA verification was made for a 50-year return wind speed. Several years after construction of the facade, no undesirable effects are occurring.

Project Outcomes

Research Advances

Although the NIDA precise nonlinear advanced analysis research software has been developing steadily for over 15 years and has proved itself valuable on many practical projects in Hong Kong and elsewhere, the team continues to pioneer improvements and greater modelling precision. All engineering analysis models are simplifications of reality and are only valid within the range of the model parameters. Models such as NIDA, however, are indeed very realistic, especially for steel structures where the material itself behaves predictably, and can represent the behaviour of structures right up to the point of collapse by taking into account structural geometric changes as well as weakening and collapsing members. One bonus for such realistic modelling is the potential to reduce safety factors and material quantities. Safety factors, of course, are always pitched on the side of caution, the amount of 'built-in caution' being usually a somewhat uncertain estimate. The more precise our models, however, the more we can be confident in those safety factors because we understand better the amount and nature of the built-in caution.

In this project a further modelling advance was in fact made. Too technical to detail in this executive report, a new form of finite element has been created to represent the imperfections which exist in real members, replacing an element which was simpler but less realistic.



Deformed Shape of Core Braced Frame

APPENDIX 1 - The Project Team Members

Project 1

Professor Heng Li	Principal Investigator
Dr G Chan	Postdoctoral Research Fellow

Project 2

Dr George Zhi-zhao Liu	Principal Investigator
Professor C Wu	Co-Investigator
Professor XL Ding	Co-Investigator
Dr WW Song	Research Associate
Miss R Xu	PhD Student

Project 3

Professor Onyx Wai	Principal Investigator
Mr Hu Wenqing	Research Assistant
Mr Li Tianzeng	Research Assistant
Mr Zhao Hongmei	Research Assistant

Project 4

Dr Y.M. Cheng	Principal Investigator
Miss SS Fang	Research Assistant
Miss N Li	Research Assistant

Project 5

Dr Yong Xia	Principal Investigator
Professor YQ Ni	Co-Investigator
Mr JZ Su	PhD Student

Project 6

Professor S.L. Chan	Principal Investigator
Dr ZH Zhou	Senior Research Fellow
Dr YP Hu	Research Fellow

Project 7

Professor Wan-ki Chow	Principal Investigator
Dr NK Fong	Co-Investigator
Dr YH Xi	Research Assistant
Dr L Qu	Research Assistant
Dr N Cai	Research Assistant

Project 8

Professor Jian-hua Yin	Principal Investigator
Dr DS Xu	Assistant Professor
Dr CY Hong	Research Associate
Dr HF Pei	Research Associate
Dr L Borana	Research Associate

Project 9

Dr Daniel W.M. Chan	Principal Investigator
Dr M Yam	Co-Investigator
Dr J Yeung	Co-Investigator (HKBU)
Dr YM Hong	Research Assistant

Project 10

Professor Geoffrey Qiping Shen	Principal Investigator
Prof XL Xue	Co-Investigator
Prof M Ashawi	Co-Investigator
Mr Zhengdao Li	PhD Student

Project 11

Professor S.L. Chan	Principal Investigator
Dr YL Wong	Co-Investigator
Dr YP Liu	Research Fellow
Dr B Li	Research Associate

APPENDIX 2 - Publications Arising from the Projects to Date

The references below enable interested readers to follow up on any project in more detail.

At this stage, the list is in embryo form only, as most projects were finished relatively recently. Several papers are still undergoing review by journals so cannot yet be referenced.

Project 1

1) Li H, Chan G, Skitmore M,"Multiuser Virtual Safety Training System for Tower Crane Dismantlement" **J. of Computing in Civil Engineering, ASCE**, Sept/Oct 2012. DOI: 10.1061/(ASCE) CP.1943-5487.0000170. American Society of Civil Engineers 2012.

Project 2

1) Rui X, Liu ZZ, Chen W "Improved FLL-Assisted PLL with in-phase Pre-Filtering to Mitigate Amplitude Scintillation effects", **GPS Solutions**, June 1-14,2014, doi:10.1007/s10291-014-0385-5.

2) Han JG, Liu ZZ, Kwon JH "Investigating the impact of Randomand systematic errors on GPS Precise Point Positioning Ambiguity resolution". **J. of the Korean Society of Surveying, Geodesy, Photogrammetry and Cartography** 32(#):233-44, 2014.

3) Liu Z, Yang Z (2015) **Anomalies in broadcast ionospheric coefficients recorded by GPS receivers over the past two solar cycles** (1992–2013). GPS Solutions. doi: 10.1007/s10291-015-0448-2.

Project 3

1) Wai O, "Extensive Green Roofs for Runoff Mitigation in a Subtropical Urban City, Hong Kong". **Urban Environmental Pollution 2014, Elsevier**. June 12 – 15, 2014.

2) Wai O, "A holistic approach for sustainable eco-flood channel design for Yuen Long Nullah" Second International Conference on Sustainable Urbanization (ICSU2015), Hong Kong, China, 7-9 Jan, 2015.

Project 4

1) Cheng YM, Au SK, Lai XL (2013b) "An Innovative Geonail System for Soft Ground Stabilization" **Soils and Foundations**, 53(2): 282-298.

Project 5

1) Su JZ, Xia Y, Chen L, Zhao X, XU YL, Ding JM, Xong HB, Ma RJ, Lv XL, Chen AR, (2013). "Long-term Structural Performance Monitoring System for the Shanghai Tower", **Journal of Civil Structural Health Monitoring**, 3(1), 49-61.

2) Su JZ, Xia Y, Xu YL, Zhao X, Zhang QL, (2014). "Settlement Monitoring of a Supertall Building Using the Kalman Filtering Technique and Forward Construction Stage Analysis", **Advances in Structural Engineering**, 17(6), 881-893.

3) Xia Y, Zhang P, Ni YQ, Zhu HP, (2014). "Deformation monitoring of a Super-tall Structure using Real Time Strain Data" **Engineering Structures**, 67, 29-38.

4) Wang L, Wang XJ, Xia Y, (2014). "Hybrid Reliability Analysis of Structures with Multi-Source Uncertainties" **Acta Mechanica**, 275(2), 413-430.

5) Xia Y, Zhang P, Ni YQ (2014) " Temperature Distribution of a Super-Tall Tube-in-tube structure in South China", 13th International Symposium on Structural Engineering, Hefei, China, 24-27 Oct, 2014,236-246, Keynote Paper.

Project 6

1) Kwan JSH, Chan SL, Cheuk JCY, Koo RCH, "A Case Study on an Open Hillside Landslide Impacting on a Flexible Rockfall Barrier at Jordan Valley, Hong Kong" Landslides, **Journal of the International Consortium on Landslides**, DOI 10.1007/s10346-013-0461-x, ISSN 1612-510X. Published on line 29/4/14.

Project 7

1) Qu L, Chow WK, "Points to note in Modelling Fire with Computational Fluid Dynamics" ASME Summer Heat Transfer Conference, 8-12 July 2012, Puert Rico, 2012.

2) Chow CL, Chow WK, "Numerical Studies on Double–Skin Facades under Fire and Wind Action "Proc. of BSA 2012 1st International Conference on Building Sustainability Assessment, 23-25 May, Porto, Portugal, 521-532 (2012).

3) Chow WK, "Mistakes made in the Application of Computational Fluid Mechanics" Hot Issues in Fire Engineering (28 March 2013), http://www.bse.polyu.edu.hk/researchcentre/Fire_Engineering/Hot_Issues.html).

Project 8

1) Yin JH, Xu DS (2014), "Application of BOTDA in Performance Monitoring of GFRP Soil Nails" Proc.of ther 5th International Forum on Opto-electronic Sensor-based Monitoring in Geo-Engineering, Nanjing, China, 12-14 Oct., 2014.

2) Zhang CC, Xu QX, Zhu HH, Zhu SB, Yin JH, (2014) "Evaluations of Load Deformation Behaviour of Soil Nails using a Hyperbolic Pullout Model" **Geomechanics and Engineering**, V.6, No.3, (2014),277-292.

3) Xu DS, Tong F, Pei HF, Yin JH (2013) "In-situ Monitoring of Internal Displacements by FBG Sensors and Slope Stability Analysis under Rainfall Infiltration" **Geotechnical Engineering Journal of the SEAGS & AGSSEA** Vol. 44, No.1, 68-77.

4) Xu DS, Yin JH, Cao ZZ, Wang YL, Xu HH, Pei HF (2013) "A New Flexible FBG Sensing Beam for Measuring Dynamivc Lateral Displacements of Soil in a Shaking Table Test." **Measurement**, V. 46, 200-209.

5) Xu DS, Borana L, Yin JH (2013)" Measurement of Small Strain Behaviour of a Local Soil by Fibre Bragg Grating Based Local Displacement Transducers. Acta Geotechnica. DOI 10.1007/s11440-013-0267-y. Published on line 2nd Aug. 2013.

6) Pei HF, Yin JH, Zhu HH, Hong CY (2013) "Performance Monitoring of a Glass Fibre Reinforced Polymer Bar Soil Nail during Laboratory Pull-out Tests using Bragg Sensing Tecnology" **Int. Journal of Geomechanics, ASCE**, July/Aug 2013, 467-472.

Project 9

1) Chan DWM, Hong YM (2014) "A Research Paradigm for Developing a Fire Risk Assessment Model for New Construction Sires in Hong Kong" Proc. Of the Third World Construction Symposium 2014 on Sustainability and Development in the Built Environment: The Way Forward (WCS 2014), 20-22 June 2014, Colombo, Sri Lanka, 26-35, ISSN 2362-0919.

Project 10

1) Li Z, Shen GQ, Alshawi M 2014a, "Measuring the Impact of Prefabrication on construction Waste Reduction: an Empirical Study in China" **Resources, Conservation and Recycling**, 91, 27-39.

2) Li Z, Shen GQ, Xue X, 2014b, "Critical Review of the Research on the Management of Prefabricated Construction" **Habitat International**, 43, 240-249.

Project 11

1) Chan SL, Liu YP, Lee A," Non-linear Analysis of a Pre-tensioned Glass Wall Facade by a Stability Function with an Initial Imperfection", **Front.Archit.Civ.Eng.**, China 2010, 4(3):376-388.

2) Liu YP, Chan SL, Zhou ZH, So D, Yu R, " Second Order Analysis and Design of Wall Framed Structures allowing for Imperfections" **Advanced Structural Engineering**, V13(3), 2010. 513-524.