Development of a Data Acquisition System and Its Use for RWCS
Principal Investigator: Appan, A
Report No: CSE/2001/74

From 1970s there has been a revival in the use of small catchments like roof areas and built-pavements for harnessing rainfall. The main objectives of this study were to appraise the quality of rainfall in the NTU campus and to develop a computer simulation model for rainwater collection systems. The model should also be capable of discretising rainfall durations and appraising the impact of such discretised data on the design parameters of the simulation model. From an analysis of rainfall data (1989 to 1994), it was ascertained that, except for pH and Coli counts, the collected rainwater was of a high order when compared to raw and treated water qualities. The average pH of 4.18 clearly indicated a degree of acidic rain and 72% of the samples had positive Coli counts. Thus, if rainwater were to be collected and used for non-potable uses, pH adjustments would have to be made. If rainwater was to be used for drinking purposes, it is strongly recommended that the full potential of this system should be investigated using all the available roof rainfalls be used for all such future analyses. Besides, a Dual Mode System (DMS) was developed ensuring that, whenever the rainwater tank was empty, potable water could be substituted. A computer program was developed to discretise rainfall duration and it was shown that rainfall data, when discretised to marginally less than 10 minute intervals, gave sufficiently accurate values for the design parameters. Using a well-used input/output model involving seven modules (NTU RWCS Mk III), a 2523 m³ rainwater tank was found to be necessary to meet all but 14.6% of non-potable uses like toilet flushing and laboratory uses. Besides, the observed hydrographs closely approximated the simulated hydrographs using the hybrid method and the triangular unit hyetographs. Close agreement was found between the simulated hydrographs using the hybrid method and the observed hydrographs.

Modelling Damage in Concrete Structures
Principal Investigator: Lee Sai Cheng
Report No: CSE/2001/76

This project investigates the behavior of partially damaged concrete beams in flexure. Damage was simulated by incorporating a recess to and beyond the longitudinal bars in the compression zone of the concrete. The experimental work involved testing of ten simply supported beams containing varying degrees of damage at mid-span, and fourteen 2-span continuous beams having similar damage details as the simply supported beams in one of the two spans. The aim was to study the effects of damage on the stiffness and strength of the member itself and on the structure as a whole, of which the damaged member was a part. Current design methods were used to predict the residual strength and flexural stiffness of beams in such circumstances, and the extent of moment redistribution in the continuous beams. Both the experimental and analytical results show consistent decrements in strengths with increasing recess depth, especially when steel bars were fully exposed. The influence of increasing recess length and decreasing reinforcement area on residual strength was less critical. The presence of recess led to reduced stiffness and the deflection profiles predicted by the stiffness equation in ACI code matched reasonably well with the test data for simply supported beams while its applicability for 2-span continuous beams was only acceptable up to the initial cracking of the concrete. Continuous beams with little damage behaved elastically up to 85% failure load, while the beams with deeper recess displayed inelastic behaviour at about 60% failure load.

Correlation of Hydrologic and Hydraulic Aspects of Urban Storm Drainage
Principal Investigator: Chui Peng Cheong
Report No: CSE/2001/75

The accuracy of the Rational method as well as the runoff coefficient and time of concentration used in the design of drainage systems was investigated. A field monitoring system comprising a number rain gauges and water level recording stations was set up in the highly-developed Stamford canal watershed to continuously collect data pertaining to rainfall and runoff characteristics. Analysis of selected rainfall and streamflow data recorded during significant storm events showed that the Rational method, which is one of the most popular and widely used drainage design methods, is consistent in the estimation of peak discharges from real storm events. The runoff coefficient and time of concentration were found to be very much storm dependent. A method incorporating the runoff coefficient and time of concentration in the Rational method with the synthetic triangular unit hydrograph was developed for the generation of complete runoff hydrographs from observed or design rainfall hyetographs. Close agreement was found between the simulated hydrographs using the hybrid method and the observed hydrographs.

Determination of Design Parameters from In-situ Tests for Land Reclamation Sites
Principal Investigator: Chang Ming-Fang
Report No: CSE/2001/77

Recent reclaimed sites in Singapore are usually covered by loose and heterogeneous fill formed by hydraulic filling and underlain by foundation soils that are dominated by the Singapore marine clay. The characterization of the foundation soils and the sand fill are critical for the development of reclaimed sites. Traditional methods of determining design soil parameters from laboratory tests on “undisturbed” samples are not always reliable and sometimes impossible, particularly for sand. One alternative is to use in-situ test methods. The success of most in-situ tests lies on correct...
interpretation of results, and yet current methods of interpretation for most in-situ tests are highly empirical, site-specific. The usefulness of in-situ tests for site characterization is therefore affected. This study aims at the development and verification of methods of interpretation for selected in-situ tests including the cone penetration test, the dilatometer test, the field vane test, the self-boring pressure meter test, the plate load test, and the seismic cone test, based on sound fundamental concepts and the elevation of the potential applicability of these in-situ tests in the characterization of geological materials at reclaimed sites. Methods of interpretation were developed on the basis of the cavity expansion theory and/or the critical state concept. In-situ test results from three recent reclaimed sites and one ongoing reclaimed site in Singapore were used to verify the validity of the proposed interpretation methods. Results of this study indicate that a theoretical framework developed by simulating the in-situ test as an expansion of cavity in modified Cam clay is useful for reliable interpretation of results from various in-situ tests for the foundation clay at reclaimed sites. With proper modification, some existing interpretation methods can be modified for estimating of design soil parameters for reclaimed sand fill, although one eventually has to rely on calibration chamber testing for verification.

Raft Foundations with Settlement Reducing Piles
– Performance and Design Considerations

Principal Investigator: Chang Ming-Fang
Report No: CSE/2001/78

Rafts have been used successfully as foundations for high-rise buildings. Although the bearing capacity requirement can be easily fulfilled, a raft may settle excessively. Several methods have been used for controlling settlements of rafts. Thickening of rafts and the use of piled rafts are the most common methods. The most effective and economical technique is, however, by means of settlement reducing piles. This study aims to investigate (1) the behaviour of rafts with and without settlement reducing piles, (2) the interaction between the raft, the settlement reducing piles and the base soil, and (3) alternative approaches to the design of settlement reducing piles. A parametric study using a two-dimensional finite element programme ABAQUS was conducted for a raft, with and without settlement reducing piles, that rests on hard clay to evaluate the influences of pile length, pile arrangement, pile number and the effect of consolidation on the performance of the raft. An alternative approach for the design of settlement reducing piles was explored and an extended analytical study was conducted to investigate its feasibility. Model piled rafts resting on sand were load tested to examine the effectiveness of settlement reducing piles in settlement control. Both the analytical and the experimental results indicate that a relatively small number of piles are required to reduce the settlements of a raft to an acceptable level. Concentrating piles within a small core area of the rafts is an effective means of reducing the settlement and the bending moment. On the other hand, an increase in pile length and the number of piles may not be effective in reducing raft settlements. By detaching piles from the pile heads, structural problems concerning the design of the piles and their connections to the raft can be overcome without affecting the effectiveness of these piles as settlement reducers.

A Study of Soil-water Characteristic Curves of Typical Soils in Singapore

Principal Investigator: E.C. Leong
Report No: CSE/2001/79

Singapore, like many regional countries, experiences many slope failures during rainfall albeit at a smaller scale. This phenomenon can be explained within the context of unsaturated soil mechanics. The change in water content of soils during rain is related to soil suction and the relationship, known as the soil-water characteristic curve, is a fundamental property of unsaturated soils. The residual soils in Singapore cover about two-thirds of the land area and are largely unsaturated. However, the unsaturated soil behaviour of these residual soils has not been thoroughly investigated. This research is an initiative to start a database on the soil-water characteristic curves of the residual soils. The scope of the research includes improving the pressure plate apparatus for the determination of soil-water characteristic curve, an investigation of the drying and wetting on the soil-water characteristic curve and the determination of the permeability function from the soil-water characteristic curve. It is also recognised that the soil-water characteristic curve has a role in vacuum preloading. The relationship between the soil-water characteristic curve and shear strength of the soft soils of the Kallang formation was examined.

Monitoring Fatigue Crack Growth in Welded Joints
Using Alternating Current Potential Drop (ACPD) Technique

Principal Investigator: Lie Seng Tjhen
Report No: CSE/2001/80

The main objective of the Applied Research Project is to study the feasibility of using the Alternating Current Potential Drop (ACPD) technique to measure the rate of fatigue crack propagation in plate-to-plate welded joints. It concentrates on the crack shapes development of 3D surface semi-elliptical cracks which are always found at the weld toe of non-load-carrying cruciform and non-load-carrying longitudinal attachment welded joints. This technique is used to measure the eight crack depths along the weld toe where probes are placed at 10 mm interval. 3D crack shapes can then be obtained at any particular cycle during the fatigue test. Sub-domain boundary element methods incorporating the transition and quarter-point elements along the crack front are used to validate the experimental stress intensity factors along the crack front. A new method for evaluating the effective stress intensity factors is proposed. A general procedure to investigate the propagation process of a 3D fatigue surface crack based on sub-domain boundary element method (BEM) is then extended in the numerical study. The mesh can be automatically regenerated as the crack propagates. The proposed formula for estimating the effective stress intensity factor is used to calculate the crack growth extension. The maximum principal stress criterion is then employed to predict the crack growth direction. Comparison between numerical and experimental results of a typical welded T-joint shows that the proposed procedure is reliable. The Alternating Potential Drop (ACPD) technique can be used to monitor any 3D fatigue crack propagation accurately.
Analysis of Frame Structures in Fire
Principal Investigator: Tan Kang Hai
Report No: CSE/2001/81

Arising from the collapse of the World Trade Centre Twin Towers on 11 September 2001, there has been a keen interest on the subject of fire resistance of structures. This is understandable as professors from MIT, North Western and UC Berkeley singled out fire resistance of steel structures as the dominant source of weakness which triggered off the domino effect of progressive collapse. At NTU, the fire engineering research has developed some useful analytical methods for the analysis of steel structures under fire conditions. The successfully developed methods comprise the finite element method, the first- and the second-order elastic-plastic hinge methods, and the Rankine approach (Ref 1-3). The plastic theorems form the theoretical basis for the development of the elastic-plastic hinge methods and the Rankine approach. The proposed finite element model (FEM) comprises the assemblage of corotational beam elements in a two-dimensional plane. Both material and geometric non-linearities are taken into account. Computer programs have been developed in-house. Comparison with test and published numerical results shows good agreement. The proposed FEM provides a practical and economical way to investigate the behaviour of steel structures under thermal effects, compared to extensive software. The Lower Bound Theorem, the Upper Bound Theorem and the Uniqueness Theorem have been successfully extended to frame analysis under thermal effects, with new definitions and mathematical proofs. The first-and second-order elastic-plastic hinge methods are developed. Both methods employ a step-wise stiffness matrix analysis incorporating the zero-length plastic hinge concept. The proposed Rankine approach allows for the interaction between strength and stability of a steel structure under thermal effects to determine an approximation of the fire resistance of members and frames. This approach is applicable for both isolated compression members and framed structures. Thus, the Rankine approach may serve as a quick tool for fire engineering design.

Assessment of Structural Condition of Bridges by Dynamic Measurements
Principal Investigator: James M.W. Brownjohn
Report No: CSE/2001/82

This report presents research carried out over a period of three and a half years aimed at developing systems to assess the condition of bridges, primarily through dynamic measurements. To this end, testing procedures, hardware and software have been developed to rank as one of the best among the handful of facilities worldwide with such capability. Procedures to integrate such data with analytical (finite element) models of bridges have been developed so that it is now possible to determine major structural details such as stiffness fixity and even load capacity from test data. In parallel with this, probabilistic procedures have been developed using mode shape and frequency data to indicate location and extent of damage, and to assess the load carrying capacity of reinforced concrete (bridge beam) members. Future research is needed to bring all these areas together through applications leading to an integrated system for condition assessment and fitness for purpose evaluation. As a start in this direction, an exercise on a short span highway bridge near NTU brings together many of these features. A separate but linked research area is the long term monitoring of new and existing bridges through analysis of static response to ambient loading. Procedures have been developed to look for performance anomalies indicating major structural changes. This research also needs to be developed, integrating data mining procedures with advanced sensors and communications systems towards an integrated structural health monitoring system. A major software system has been developed for system identification involving manipulation of modal test data and correlating with analytical solutions.

Parametric Study of Welded Tubular Joints (St &ME)
Principal Investigator: Soh Chee Kiong
Report No: CSE/2001/83

Tubular joints have been widely used in onshore and offshore structures. However, the guidance for the design of welded multiplanar joints is still insufficient because of the lack of test data. Therefore, in this study, experimental and numerical research has been carried out to increase the data on the ultimate strength of multiplanar joints and to provide a better basis for the design of multiplanar joints. In the experimental research programme, one full-scale multiplanar XX-joint and one XT-joint were tested to produce more knowledge on the behavior and failure modes of the joints. According to the comparison with uniplanar joints and previous test results, it is observed that the compressive loads on the out-of-plane braces actually improved the ultimate compressive strength of the corresponding uniplanar joints, while tension loads have an opposite effect. Furthermore, the AWS code has been shown to be conservative in predicting the ultimate strength of multiplanar XX- and XT-joints. The numerical studies on multiplanar XX and XT-joints were also calibrated against the experimental results. Good agreement between the load-displacement curves of the numerical work and the experiments were observed, and confirmed that the FE method is reliable in predicting the ultimate strength of tubular joints. Furthermore, parametric studies on multiplanar XT-joints have been carried out. The influence of the geometrical parameters $\theta$, $\phi$, $2\theta$ and $\phi$ and the load ratio between the load on the out-of-plane brace and the in-plane brace, have been determined for various types of loads. A formula has been developed to predict the ultimate capacities of multiplanar XT-joints, and has been compared with the AWS code and the predictions of Vege(1995).

Geotechnics of Reclaimed Land
Principal Investigator: Teh Cee Ing
Report No: CSE/2001/84

This report describes the determination of engineering soil parameters for the foundation clay and for the reclaimed sand fill at the Changi east reclamation site from laboratory tests, in-situ tests and field monitoring. For the characterization of the Singapore marine clay underlain the reclaimed site, methods have been proposed for the interpretation of engineering soil parameters from results of various in-situ tests. The undrained shear strength interpreted from the piezocene test, as well as from the
self-boring pressuremeter test, is comparable to the laboratory shear test and field vane test data. The preconsolidation pressures back calculated from field measurements are comparable with the results of oedometer tests. The compression index obtained from the oedometer test is smaller than that back-calculated from field measurements due to creep of the clay. Methods have also been proposed for the estimation of overconsolidation ratio of the natural clay from the piezocene test, the dilatometer test, the self-boring pressuremeter test and the field vane test, and the interpreted results compare well with data from oedometer tests. Results of laboratory test and field measurement indicated that the coefficient of consolidation for horizontal drainage is about 1.5 times that for vertical drainage for the foundation clay at the Changi east reclamation site. Methods have also been proposed for the assessment of the degree of consolidation of the foundation clay at the reclamation site from the piezocene test and the field vane test and the results are comparable with field measurements from piezometers and piezocene dissipation tests. For the characterization of sand fill at the reclaimed site, methods have been proposed for the estimation of stiffness parameters from the self-boring pressuremeter test and the piezocene test in sand. The relative density of sand can also be estimated from the result of piezocene test based on a proposed correlation.

Sorption and Speciation of Heavy Metals in a Marine Clay

Principal Investigator: Teh Cee Ing
Report No: CSE/2001/85

This study was funded under Applied Research Project RP 16/92. The experimental works associated with this study were conducted in the School of Civil and Environmental Engineering, Nanyang Technological University. The capability of a marine clay to immobilise Zn, Pb, Cd, and Cu was assessed in the laboratory under acidic, neutral, and slightly alkaline conditions. The heavy metal speciation in the marine clay was investigated and their retention modes in the soil were suggested. The geo-environmental properties of the marine clay were also assessed. The investigation was carried out through batch sorption experiments. A background electrolyte was introduced in each sorption test. The background electrolytes used in this study were NaCl and CaCl₂. The heavy metals retained by the marine clay were fractionated into exchangeable, carbonate, reducible, organic and residual fractions using a sequential extraction technique. The influence of the following factors on the heavy metal sorption and speciation in the marine clay was assessed: (1) pH; (2) NaCl and CaCl₂ background electrolytes; (3) ionic strength; (4) competitive sorption among the heavy metals in various multi-element mixtures; (5) the heavy metal loading on the marine clay; and (6) sorption period. The results of investigation indicated that the heavy metal speciation in the marine clay depended significantly on soil pH. Between the slightly acidic and slightly alkaline conditions, the heavy metals were predominantly retained in the carbonate and reducible fractions, whereas the exchangeable sorption could be of relatively greater importance in acidic conditions. The portion of heavy metals retained in the residual fraction could also be important, and this fraction was less influenced by the pH value. The organic component in the marine clay was of the least importance in immobilising the heavy metals. There was greater sorption of the heavy metals in the NaCl medium than the CaCl₂ medium, primarily due to the reduction in exchangeable sorption in the latter medium. The sorption decreased with increasing NaCl and CaCl₂ concentrations. On the other hand, the presence of various heavy metals in solution did not seem to significantly interfere the sorption and speciation of each heavy metal in the marine clay. However, the level of the heavy metal loading could affect the metal speciation in the soil. Results of time-dependent sorption tests for a period of up to 65 days indicated that the heavy metal sorption in all except the organic fractions changed with time. The trend and degree of changes were dependent on pH. Since the speciation of heavy metals in a soil can change with changing environmental condition, the persistency of the metal sorbed phases in the dynamic soil environment should be understood. Total metal sorption measurement is therefore inadequate for the metal mobility study. In this context, this study has significantly enhanced our understanding of the potential mobility and the mode of retention of various heavy metals under varying soil conditions. Although only the marine clay was investigated, the findings can be also qualitatively applicable for other soils since metal-soil interactions involved similar mechanisms regardless of the soil type.

Rainfall-Induced Slope Failures

Principal Investigator: Harianto Rahardjo
Report No: CSE/2001/86

Two-thirds of Singapore’s land area is covered with residual soils from the sedimentary Jurong and the granitic Bukit Timah formations. Rainfall-induced slope failures often occur in these residual soils as a result of tropical rainfall events. These slope failures can be dangerous, disruptive to development of infrastructure and costly to repair. An appropriate design philosophy can be adopted if the mechanism of rainfall-induced slope failures is understood. The main objectives of this study were to determine the mechanism that leads to rainfall-induced slope failures in residual soil, to develop guidelines for stability assessment against such failures in Singapore and to evaluate several possible preventive measures. The mechanism of rainfall-induced slope failures was studied extensively using four fully instrumented slopes in the sedimentary Jurong and the granitic Bukit Timah formations in Singapore. The result of the study has been disseminated in a monograph. Initially, downward infiltration of rainwater can cause the development of a perched water table in the zone of approximately 3m below the slope surface. Subsequent water flow through the perched water table is mainly in the downslope direction. Design charts for preliminary stability assessment of typical slopes during rainfall have been made available in the monograph. Engineered soil covers can be designed to limit infiltration during wet periods while still allowing for evaporation during dry periods. Research in the area of engineered soil covers or capillary barriers for slope stabilization is underway at NTU in order to develop viable options for the local soils and climatic conditions in Singapore.
Evaluation Model of the Durability of High Performance FR Concrete in a Marine Environment  
Candidate: Jiang Jiabiao  
Report No: CSE/PhD/2000/27

This study aimed at establishing an evaluation model of concrete durability in a marine environment in respect of chloride penetration, which is caused by diffusion and cycles of drying and wetting. An electrically accelerated method has been proposed to measure the diffusion coefficient of chloride in concrete and to investigate the influencing factors. In this proposed method, Neinst-Einstein equation was adopted to relate the diffusion coefficient to the rate of chloride migration under electric field. For calibration purposes, real time diffusion tests were carried out to validate the accelerated method. Simple methods for determining the sorptivity and moisture-dependent diffusivity in concrete were proposed as well. Based on analysis of mechanisms of diffusion of chloride and moisture transport, a mathematical model of chloride penetration by coupling these two processes together has been established. Experimental programmes were carried out to verify the proposed coupled model, where the initiation period for corrosion of reinforcement could be evaluated.

Development Of Adsorbents From Municipal Sewage Sludge  
Candidate: Chen Xiaoge  
Report No: CSE/PhD/2000/28

The primary aim of this research was to develop carbonaceous adsorbents from municipal sewage sludge for the treatment of waste streams. Carbonisation and chemical activation with ZnCl₂ were employed to prepare adsorbents from sewage sludge and the mixtures of sewage sludge with coconut husk and peanut shell. The preparation condition parameters, including ZnCl₂ concentration, final heating temperature, holding time, heating rate and the mixing ratio of additive (coconut husk or peanut shell) to sludge, were varied and controlled. The results reveal that these parameters could affect the adsorptive properties and performances of the produced adsorbents. The produced adsorbents had a well-developed porosity with a variety of oxygen-containing functional groups on surface. The heavy metals in the adsorbents, with the exception of Zn, were not readily leachable. The aqueous adsorption tests demonstrate that these adsorbents were adsorptive of various organic pollutants, particularly the substituted phenols and organic dyes. The pyrolysis processes of sewage sludge with and without ZnCl₂ activation were monitored using a TGA-FTIR hyphenated technique for the mechanism study. The pyrolysis mechanism with three global stages of degradation reactions was speculated based on the observations. Accordingly, a kinetic model of four consecutive competitive reactions was developed to simulate the pyrolysis processes. Satisfactory fitness was achieved between the proposed model and the experimental data.

Stability Study of High-Rate Anaerobic Systems  
Candidate: Zhan Xiyue  
Report No: CSE/PhD/2000/29

The stability of three major high-rate anaerobic treatment systems, including anaerobic fluidized bed reactor, anaerobic filter, and upflow anaerobic sludge blanket reactor, subjected to various shocks was extensively investigated. A fuzzy stability index was proposed to explicitly indicate the system departure from normal operation state. Based on the experimental results and the fuzzy index, stability of the three systems were quantitatively compared. The comparison revealed the differences and similarities between the behavior of different systems in the presence of various shocks. Based on the adaptive network-based fuzzy inference systems (ANFIS), a conceptual neural fuzzy model for anaerobic wastewater treatment systems was developed. The model successfully combined the merits of both neural networks and fuzzy systems, and showed great adaptability in the simulation and prediction of the performance of either steady state or unsteady state systems.

Behaviour of DCM Columns under Highway Embankment at Bridge Approaches  
Candidate: Lin Kai Qiu  
Report No: CSE/PhD/2000/30

A large post-construction differential settlement between a bridge and the backfill behind the abutment has been the major problem in the construction of highway embankment over a soft clay foundation. The use of soil-cement columns formed by deep cement mixing (DCM) can be an economical and effective soil improvement method to minimise the settlement and to improve the slope stability. This study examines the various factors which may affect the behaviour of the soft soil foundation stabilised by the soil-cement columns based on (i) field study of a trial embankment; (ii) large scale model tests and (iii) numerical studies using the finite element method. The factors considered in this study are column stiffness, column spacing, characteristics and thickness of the soft clay layer, compressibility of the bearing stratum, presence of geotextile, properties of embankment fill and the interaction between the columns and the surrounding soils. Design charts have been developed for the design of the DCM columns end-bearing on a hard stratum under a highway embankment.

Effects of Construction Methods and Concrete Cracking on the Performance of Propped Diaphragm Walls  
Candidate: Poh Teyh Yaw  
Report No: CSE/PhD/2000/31

Diaphragm walls are increasingly being used in Singapore for supporting propped excavations. Currently there are some uncertainties regarding the design of diaphragm walls in Singapore. Two of these aspects are the effects of concrete cracking and wall installation. In this research, three case histories of propped excavations have been back-analysed and extensive parametric studies have been conducted to study the effects of concrete cracking on their performance. Also, case histories of wall construction in Singapore soil conditions

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as well as a well-instrumented field trial of wall construction are evaluated to provide a better understanding of the effects of the wall construction on adjacent ground deformations and changes in lateral earth pressures. Soil improvement methods such as jet grouting are commonly used in Singapore to improve the strength and deformation characteristics of soft soils before the start of the excavation. The process of jet grouting involves high-pressure operations, which tends to displace the adjacent soil away from the grouted zone. The performance of a well-instrumented jet grout trial and the production grouting at a site in Singapore are evaluated to investigate the effects of jet grouting on the diaphragm walls, adjacent ground, and nearby structures.

Evaluation of Load Transfer Behaviour of Bored Piles in Residual Soils Incorporating Construction Effect
Candidate: Zhu Hong
Report No: CSE/PhD/2000/32

Extensive laboratory and in-situ tests were carried out to investigate the effects of bored pile construction, particularly those resulting from soaking, on shear strength and deformational properties of the residual soil of Jurong Formation in Singapore. The soaking effect was also examined based on results obtained from tests on model piles and full-scale piles installed in the Jurong Formation. Effects of different construction procedures on stress distributions around a shaft were studied by both numerical and theoretical analyses. The shear strength and the deformational properties of the residual soil were found to deteriorate with soaking. The horizontal stress in the surrounding soil adjacent to the pile shaft did not return to its original state after pile construction. A procedure that accounts for the nonlinear decrease of modulus with an increase in strain/stress level and construction effect has been proposed for the analysis of load transfer along a bored pile. The predicted load transfer curves were found to compare well with results of load tests on instrumented bored piles.

Damage Assessment of Reinforced Concrete Structures Subjected to Ground Excitations
Candidate: Ma Guowei
Report No: CSE/PhD/2000/33

The primary objectives of the present study are: 1) to develop a reliable numerical method to simulate underground explosion, 2) to investigate damage of surface structures subjected to blast-induced ground motions, and 3) to derive desirable inhabited building distance of various structures located on the surface area near underground ammunition storage. To serve the three objectives, numerical simulation of underground explosion, damage assessment of structures subjected to high frequency ground motions, homogenization of masonry and investigation of masonry effects on structural response were carried out. A plastic-damage model, which is pressure and strain-rate sensitive was proposed to simulate rock mass failure induced by underground blasting. A large-scale underground explosion is analyzed by using the validated numerical model. Corroboration of the numerical results, such as attenuation of peak particle velocity, ground motion histories, rock damage around the blasting chamber and safe separation distance of adjacent chambers, with experimental results are discussed. Damage assessment at material level was proposed in the present study to model distributed damage in structural element induced by high frequency vibration. A fracture indicator and a plastic indicator were defined to reflect fracturing of concrete and yielding of reinforcement. The numerical model was calibrated by shaking-table test data of a 1:5 scale single-storey frame. Suggestion was made to evaluate global damage of entire structure based on material damage through analysis of numerical results and shaking-table test data. Major, moderate and minor damages of structures were defined quantitatively according to the global damage index. In order to estimate dynamic response and damage of masonry infilled in a RC frame under blastinduced ground motion, a homogenized material model for masonry was derived and calibrated with laboratory test results. Parametric study was carried out regarding RC frame with or without masonry wall, and its different surface distances. Desirable inhabited building distances of these structures were then derived numerically.

Behaviour Of Sandwich Panels
Candidate: Cheng Qianhua
Report No: CSE/PhD/2000/34

A new truss-core sandwich panel structure is presented. This construction is similar to other sandwich forms but is more advantageous in terms of fabrication and stiffness-to-weight ratio. A simplified analysis method was investigated in which the 3-D panel is transformed into an equivalent 2-D orthotropic thick plate continuum. Derivation of the equivalent elastic constants is presented. By incorporating the elastic constants to a small-deflection theory, bending and vibration problems of sandwich panels are investigated. The Rayleigh-Ritz method is used to develop closed-form solutions. Computed results by the closed-form solution are in good agreement with finite element methods. Elastic and elastoplastic responses of the panel to air-blast loading are investigated. The panel is transformed to an equivalent SDOF system and the elastic solution is obtained by the Duhamel integral. The yield line theory is applied to derive the elastoplastic properties and the response is obtained by a numerical integration scheme.

Knowledge-based Parametric Design and Collaboration
Candidate: Wang Zhonghui
Report No: CSE/PhD/2000/35

Parametric design is a promising technique for engineering applications. Various approaches in this area have been carried out for years, and several kinds of constraint algorithms have been produced, such as numeric solvers, constructive solvers, symbolic algebraic solvers and knowledge-based solvers. These solvers can deal with certain problems while leaving others unsolved, for example, the ability of knowledge-based solvers for under-constrained problems is still in its infancy. This research first presents a novel approach based on constraint networks to extend the use of knowledge parametrization for under-constrained problems. Meta-level rules of Minimal Modification and Constraint Weight have been introduced to manage and process constraints.
Complicated constraint relationships such as multi-arc tangent connection are discussed. Constraint graph reasoning and propagation are used in the new model generation. Since very few applications of parametrization have been found in civil engineering, the first example for preliminary structural design is presented to demonstrate the algorithm’s efficiency and prospect in civil engineering problem solving. The second example demonstrates the feasibility of the proposed method for both under-constrained and well-constrained problems. In the design activities, design changes in a multi-view model also occur quite frequently. However, issues of multi-view geometric problem have not attracted adequate attentions in the design field. This study attempts to solve multiple-view problems by incorporating the technique of constraint-based parametrization for single 2D model with the proposed concepts of entity influence lines. Based on the descriptive geometry, entity projection rules and reasoning rules are incorporated to deal with the multi-view constraint schema. The multiview model to be addressed is expressed in three orthographic views, and illustrative examples are presented to show the practicability of the method. Coordination of design information is essential for the design team to provide accurate technical documents for the actual construction. Design changes between different models are inevitable during any ordinary building project, for various reasons. If the design changes are not properly managed, design conflicts will be created, which will result in more expensive designs or even failure in the design-construction process. However, few researches have addressed the issues to provide assisting tools for the management of design changes. Therefore this study continues to present an approach on parametric coordinator that can facilitate the coordination of design information through managing design changes. Design changes of dimensions between different building components are specially discussed. The proposed parametric coordinator is based on the earlier research work for knowledge-base constraint solver, and is enhanced with a set of managing tools. This coordinator provides each building component with the linked knowledge, which can be described in a dimensional property and a reference property. A group pattern module is applied to check the design consistency. Illustrative examples are presented to demonstrate the feasibility of the proposed method for managing design changes between different models.

Response Of Steel Fibre Reinforced Concrete
Candidate: Xiao Jiarun
Report No: CSE/PhD/2000/36

In this study, a static uniaxial constitutive model for steel fibre reinforced concrete (SFRC) is investigated. Based on the proposed constitutive model, the full flexural moment-curvature response of SFRC is derived. The flexural response of bar reinforced thin SFRC panels is also presented. The relationship between tensile and flexural behaviour of SFRC has been developed. This relationship enables the rapid determination of the strength of SFRC. An SDOF model was developed to analyse the dynamic response of SFRC panels subjected to air-blast loading. Influence of membrane action on restrained slabs is examined. Details of an experimental investigation on SFRC specimens and panels are presented. A total of 90 different standard specimens and 42 panels, including plain concrete, conventional weldmesh reinforced concrete and SFRC reinforced with three different types of steel fibres and three different volume concentrations, have been tested under static load and blast load, respectively.

Integrated Coastal Resource Management Using Geographic Information System
Candidate: Sia Sheau Yunn
Report No: CSE/PhD/2000/37

As an island nation, Singapore is heavily dependent on its maritime activities. It is enhanced by its strategic location at the crossroads of the trade routes linking the Asia Pacific region to West Asia and Europe. Despite its limited coastal zone, Singapore has been extensively developed for port and shipping activities. As the traffic volumes continue to rise in the busy sea-lanes, the port waters of Singapore and the region has become more vulnerable to oil spills that either caused by vessel collisions and/or sludge dumping. Oil spill can have a serious economic impact on coastal activities and users. This study aims to develop an “Expert-like” management system, Integrated Coastal Resource System (ICRM), specifically for the management of oil spill, response to the accident, and combat strategy. The system includes, at this steps of development, a numerical simulation, GIS and oil spill response module. An example oil spill incident is illustrated.

Investigations Of Buoyant Jet Discharges Using Digital Particle Image Velocimetry (DPIV) And Planar Laser Induced Fluorescence (PLIF)
Candidate: Wang Hongwei
Report No: CSE/PhD/2000/38

A combined Digital Particle Image Velocimetry (DPIV) and Planar Laser Induced Fluorescence (PLIF) system has been developed for the measurements of both time mean and turbulent mass transport in mixing processes. The system couples the two well-known techniques to enable synchronised planar measurements of flow velocities and concentrations in a study area. Various considerations in this combination are described. The potential interference effect between the seeding particles for DPIV and the fluorescent dye excitation for PLIF was carefully investigated. The mean and turbulent properties of vertical round jets, plumes and buoyant jets during the transition from jet to plume were investigated thoroughly using the developed combined system. Based on the experimental findings, a refined integral model of buoyant jets that achieves second-order conservation of mass and momentum fluxes is proposed. Unlike most existing integral models, the mass and momentum fluxes contributed by turbulence are appropriately accounted for in the proposed model.

Consolidation of Soft Clays Around Vertical Drain
Candidate: Nie Xiaoqian
Report No: CSE/PhD/2001/39

The combination of vertical drains with precompression by surcharge loading is an effective soil-improvement method
and has gained wide interest and recognition. In this study, a numerical method is proposed for the analysis of the consolidation around vertical drain. The variation of soil permeability during the consolidation process was taken into account in the formulation. In addition to the traditional Darcy’s law, the non-Darcian flow proposed by Hansbo, was also incorporated in this study. The finite element program was developed within the framework of the coupled consolidation theory using the modified Cam-clay model. Parametric studies were conducted to investigate the influence of non-Darcian flow and variation of soil permeability on the consolidation process. It was found that the consolidation rate would be retarded when non-Darcian flow is considered. When the threshold hydraulic gradient $i_i$ is small, the influence of non-Darcian flow on consolidation is almost negligible. For $i_i \geq 40$, the consolidation rate would slow down significantly. The changes in soil permeability were correlated to void ratio (with change index $C_{pk}$) or stress level (with change index $C_{tk}$). The consolidation process was found to slow down with increase in $C_{pk}$ or decrease in $C_{tk}$. The consolidation rate would be retarded significantly for $C_{pk}$ values larger than 1.5 or $C_{tk}$ values less than 1.0. The permeability can be taken as constant when $C_{pk} \leq 0.5$ or $C_{tk} \geq 2.0$. Inclusion of non-Darcian flow, permeability variation, and their combined effect does not significantly influence the patterns of deformation and excess pore pressure. The results of numerical analyses show that the stress history and preconsolidation pressure have significant influence on the consolidation behaviour of the soils, particularly on the dissipation of excess pore pressure. In measuring the rate of consolidation, a unambiguous definition of the degree of consolidation, either in terms of excess pore pressure, or in terms of settlement, is very important, particularly for plastically deforming clays. The back-analysis of two case histories show that the numerical model was able to capture and reproduce the essential consolidation characteristics. The numerical model yields reasonable predictions of the settlement- and excess pore pressure-time behaviour.

Static Behaviour of Steel In Beam to Concrete Filled Tube Column Connections
Candidate: Dai Chaowei
Report No: CSE/PhD/2001/40

Steel I-beam to concrete filled tube (CFT) column connections offer a number of advantages for design and construction, and can be used in a diversity of application. However, insufficient design information is available for this type of composite connection to date. In order to obtain more understanding and deeper insight into the static behavior of such composite connection to form a basis for its design, experimental and numerical investigations are carried out in this research report. Finite element models of these connections were established. The validity of these numerical models was demonstrated by comparisons with experimental result and theoretical analyses. On the basis of the results obtained from the numerical analysis, an experimental program was planned. A total of 19 CFT column specimens, 3 steel connection specimens and 21 CFT connection specimens were designed and tested to failure in this program. Based on the numerical analysis results and experimental results, unified moment resistance and rotational stiffness empirical formulae were developed for the composite connections with or without stiffening details. The validity of the unified empirical formula was confirmed by experimental test results. In addition, a tri-linear model was proposed to simulate the complete moment-rotation relationship of the composite connection under consideration. Comparison study showed that the proposed moment-rotation curves were very close to the moment-rotation curves obtained from the experiments.

Parametric Stress Analysis of Steel Multi-Planar Tubular XT- and XX-joints
Candidate: Wu Naiwen
Report No: CSE/PhD/2001/41

In this thesis, large-scale steel tubular XT- and XX-joint specimens were designed following the current industrial provisions. The stress concentration factors (SCF), strain concentration factors (SNCF) and the SCF to SNCF Ratios (S/N Ratio) at typical crown and saddle hot spot locations were investigated experimentally under various basic axial and axial combined with In-Plane-Bending (IPB) and Out-of-Plane-Bending (OPB) load conditions. The average SN Ratio values of 1.16 and 1.14 were derived for the tubular XT- and XX-Joint specimens. Large amount of multiplanar effects were revealed from the experimental study. The steel multiplanar XT- and XX-Joint specimens had been modeled using the FEM. The good agreement between such numerical SCF results and the experimental results proved the reliabilities of the numerical modeling of the steel multiplanar XT- and XX-Joints. Based on the verified numerical models of the multiplanar tubular joints, parametric stress analyses were carried out for 84 multiplanar tubular XT-joints and 64 XX-joints. Based on the database of hot spot stresses obtained from about 1000 runs of three-dimensional finite element stress analysis, general SCF design equations were established for the XT- and XX-joints for the basic axial and bending load cases. The assessment results proved that the proposed SCIT design equations for tubular XT- and XX-joints were acceptable judged by the new DEn criteria. By analyzing the multiplanar effects between the multiplanar tubular XT- and X-joints, a Unified T joint model was established. A set of Unified SCF Equations was derived through the FEM SCF databases of the XT- and XX-joints. Based on the superposition method, the Unified SCF Equations were capable in calculation the SCFs for the uniplanar T- and X-joints, and the multiplanar V-, XT- and XX-joints under arbitrary load conditions. The Unified SCF Equations were also assessed using the available SCF or SNCF test results obtained mainly from the large-scale steel T-, X-, V-, XX- and XT-joint specimen tests. The assessment results confirmed the reliability of the Unified SCF Equations.