Deformation of Ultra Soft Soil
Principal Investigator: Bo Myint Win
Report No: CEE/PhD/2002/59

The formation of an alluvial clay deposit normally goes through sedimentation and consolidation. While the bottom portion is undergoing self-weight consolidation, sedimentation continues to take place at the top. However, the deformation behaviour of such deposits upon loading is not well understood. This study investigated the deformation behaviour of ultra-soft soil upon additional load application. Various types of laboratory compression tests were conducted, such as tests using small and large-scale consolidometers, hydraulic Rowe cells under different drainage conditions, Constant Rate of Loading and Constant Rate of Strain tests. Attempts were made to determine the transition point between viscous and plastic deformation. Relationships between the void ratio at a transition stress of 10 kPa and the liquid limit were established. Methods to determine the compression indices and coefficients of consolidation at different stress ranges were developed. An equation for predicting settlement of ultra soft soil in both the viscous and soil stages is proposed and an implicit finite difference model was developed using the large strain consolidation theory proposed by Gibson et al. (1967). The proposed methods were validated against published data, laboratory measurements and a case study.

Progressive Collapse of Steel Frames in Fire
Principal Investigator: Huang Zhanfei
Report No: CEE/PhD/2002/60

In this research, both numerical and analytical approaches are used to investigate the progressive collapse of steel columns and beams within a non-sway steel frame subjected to localised fire attack. The numerical work consists of the following three parts. Firstly, finite element program FEMFAN (Version 2) is developed to be able to perform visco-elasto-plastic analysis for skeletal steel frames. A series of benchmark tests are conducted to verify FEMFAN. Secondly, subframe and isolated column/beam models are proposed to predict the behaviours of heated compartments within a steel frame. Comparisons of the results obtained by full-frame, subframe and isolated member analyses show that the proposed simplified models can accurately predict the structural responses of fire compartments as well as steel column/beam critical temperatures. The limitations of the proposed models are also presented. Thirdly, on the basis of proposed isolated column/beam model, an extensive study is conducted to investigate the progressive collapse of heated steel columns and beams subjected to elevated temperatures. The parameters include the boundary axial/flexural restraint ratio, external load utilisation factor, member slenderness ratio, and cross-sectional thermal gradients etc. Semi-rigid springs are adopted in the steel beam parametric study to approximate the beam-to-column connections. Member critical temperatures obtained by numerical analyses are tabulated for design purposes. Besides, creep effects on the structural responses of heated members and their critical temperatures are examined. They illustrate that creep starts to dominate the structural response of a steel structure beyond 400°C. In the analytical aspect, traditional Rankine equation is extended to predict the critical temperature of a steel column within a fire compartment in a frame. Both the creep strain and the boundary restraints are considered in the formulations. Extensive comparisons between the predictions of proposed Rankine formulas and FEA show that for the most cases under study, the Rankine approach yields accurate and conservative column critical temperatures.

Automated Incident Detection on Expressways
Principal Investigator: Mak Chin Long
Report No: CEE/PhD/2002/61

The main objective of this study was to develop automated expressway incident detection algorithms for Singapore conditions, which are also transferable to other sites. The study used extensive real-world incidents collected from the Central Expressway (CTE) in Singapore and Melbourne freeways. Two new detection algorithms: the Dual Variables (DV) and the Combined Detector Evaluation (CODE) were successfully developed for Singapore conditions to receive wide-area traffic inputs from a single-station and dual-station model structure, respectively. These algorithms yielded remarkable improvements in effectiveness over the conventional algorithms (Standard Normal Deviate and Minnesota), as well as satisfying the average acceptable limits of several traffic management centres in the USA. From an efficiency perspective, the algorithms are capable of detecting an incident within 2.5 minutes after it had occurred, similar to that of existing detection algorithms. The DV and CODE algorithms out-performed the conventional algorithms (Standard Normal Deviate and California Algorithm #7) and the ARRB/VicRoads Model when applied on Melbourne freeways. The algorithms can also achieve equally good performance as the ANN-based model that was developed using the same database.

Genetic Programming for Structural Optimization and Design
Principal Investigator: Yang Yaowen
Report No: CEE/PhD/2002/62

This study introduces genetic programming (GP) into civil engineering problem solving as a search and optimization method, and investigates the applicability of GP-based approach to civil engineering problems, especially to structural optimization and optimum design problems. First, an encoding strategy is presented to map between the real structures and the GP parse-trees. Then a GP-based methodology for simultaneous sizing, shape and topological optimization of structures is proposed and extended for the automated optimum design problems. Finally, in order to improve the performance of GP, a fuzzy logic integrated GP-based methodology, which incorporates the expert knowledge and experiences, is presented. A computer-based biological evolution procedure prototype system for the proposed approach has been developed using C++. Illustrative examples presented show the effectiveness and the efficiency of the approach.

Limit and Shakedown Analysis of Tubular Joints
Principal Investigator: Yu Shengkai
Report No: CEE/PhD/2002/63

The objective of this study is to develop an efficient numerical method and a rational analytical model for predicting the ultimate strength of tubular joints. The limit and shakedown analysis theorems were used to perform the numerical simulations and construct the analytical model. A numerical method for the lower bound limit analysis of rigid-perfectly plastic structures was developed based on optimal stress recovery techniques. Then this method was applied in the numerical studies of tubular X- and T-joints subjected to AC or IPB loads. Another numerical method was also developed for the upper and lower bound shakedown analysis of elastic-perfectly plastic structures subjected to variable repeated loads. The shakedown analysis of X- and T-joints under
Combination of AC and IPB loads was carried out, and the influence of variable repeated loads were investigated. Finally, two analytical models were developed based on the yield line method and the observed failure mechanism. Good correlation was achieved by comparison with the experimental results.

**Quantitative Relationship between Permeability and Pore Structure of Cement Paste and Mortar**

*Principal Investigator: Cui Lu*

*Report No: CEE/PhD/2002/64*

This thesis tried to establish the relationship between the water permeability of cement paste and mortar with their pore structures. It found that the cement paste should be regarded as a bi-composite material, which includes the high permeable phase (includes capillary pore) and low permeable phase (includes gel pores). The contribution from these two composites to the overall permeability of cement paste can be calculated by general effective medium theory. It also proposed the two-phase model for the porous mortar (capillary cement paste in mortar > 20%) and three-phase model to predict its water permeability. Asymmetric effective medium theory and self-consistent effective medium theory have been used to calculate the permeability. Finally, the effects of silica fume on the permeability models have been analyzed. The experimental data and other researchers’ data have been used to prove the models.

**Biological Nutrient Removal Using Fixed-Bed Filters**

*Principal Investigator: Li Huihua*

*Report No: CEE/PhD/2003/65*

In this research, a series of laboratory studies on the conventional A/O process using a fixed-bed filter were carried out. The aim was to evaluate and to model the performance of the fixed-bed filter in treating a medium strength wastewater. The performance of this filter was investigated through two series of orthogonal tests and four loading tests. Factors having influence on its performance, such as COD:N:P ratio, effluent recycled from the settler to the anoxic zone, sludge recycled from the settler to the anaerobic zone and from the anaerobic zone to the aerobic zone, and dissolved oxygen concentration, were investigated. All these factors except for COD and N concentrations were found to have a significant influence on nutrient removal. The filter was able to remove both nitrogen and phosphorus efficiently under optimal conditions. A mathematical model was also developed to simulate the dynamic behaviour of the filter and biomass growth. Close agreement between the model predicted results and the experimental measured data indicated good predictive capabilities of the dynamic model.

**A Micromechanics-Based Constitutive Model and its Application to Lattice Analysis of Plain Concrete**

*Principal Investigator: Li Qingliu*

*Report No: CEE/PhD/2003/66*

The main purpose of this research is to develop a micromechanical constitutive model for concrete, which is able to explain the relationship between the macroscopic characteristics and the microstructure of brittle composite material such as concrete. In the current thesis, a theoretical micromechanical model based on the Mori-Tanaka method and the spring-layer model is developed to study the mechanical behaviour of concrete. The concrete material is modelled as a three-phase composite material consisting of mortar, coarse aggregates and imperfect interfaces between them. The failure of concrete is categorized into two types: mortar failure and interface failure. Comparison with experimental data shows that the proposed model is reasonably good. Concurrently, a numerical model based on the new theoretical micromechanical model and lattice models has been proposed to simulate the fracture behaviour of concrete specimens. Close agreement between the numerical results and the experimental data in literature indicates that the model is reasonably good, even in predicting crack development. The numerical lattice model can, therefore, be an effective and useful tool for the analysis of the micro-structural behaviour.

**Numerical Split Hopkinson Pressure Bar (NSHPB) Test and its Applications in the Assessment and Improvement of SHPB Test Results**

*Principal Investigator: Meng Hui*

*Report No: CEE/PhD/2003/67*

Split Hopkinson pressure Bar (SHPB) has become a frequently used technique for measuring uniaxial compressive stress-strain relation of various engineering materials at high strain rate. However, the reliability of this technique when it is applied to test non-metallic materials needs to be examined. A NSHPB test may overcome many practical difficulties of stress/strain measurements, and therefore, can be used to assess the reliability of a SHPB test, to correct measurement errors and to recommend further modifications and improvements. Based on the proposed Non-Uniform Coefficients Method and NNSHPB tests, a general procedure for the numerical assessment and correction of SHPB results is suggested. Experiments on the kinetic friction measurement are conducted to construct a friction model to relate the kinetic friction coefficient to relative velocity. A modification of SHPB set-up is developed to effectively reduce the possible wave dispersion and attenuation in the pressure bar. The proposed NSHPB testing method is applied to concrete-like materials and cellular materials. It shows that pseudo strain-rate effects may exist in SHPB tests for those non-metallic materials.

**Corrosion of Reinforcement - an Application of Concrete Technology from Theory to Practice**

*Principal Investigator: Mohamed Abdelkader Edgelany Ismail*

*Report No: CEE/PhD/2003/68*

Corrosion of steel reinforcement in concrete initiated by the ingress of chloride is one of the main factors causing deterioration and damage of concrete structures all over the world. The aim of this study was to focus on the gray zone between the initiation and propagation period, which together form the service life of the concrete structure and to investigate corrosion of steel reinforcement in concrete specimens under controlled exposure conditions by using electrochemical techniques. Three different parameters were used in this study. The first parameter was two types of concrete mixes OPC and HPC. The second parameter was four different concentrations of sodium chloride solution 0%, 1%, 3% and 5%. The third parameter was four types of curing conditions, which were in-door laboratory, out-door, oven drying and immersing in solution all the time. Precautions were taken to ensure that no other irrelevant conditions affect the study including rust, noise, and concentration of solutions. Tafel plot, linear polarization resistance and impedance spectroscopy techniques were used to assess corrosion and determining corrosion rate for each of the used specimens. For impedance spectroscopy, equivalent circuit was used for modelling the Nyquist plot of real and imaginary impedance. The electrochemical parameters calculated were used to explain the behaviour of specimens under corrosion. It was found that high performance concrete specimens achieved better results compared with ordinary concrete specimens in terms of the corrosion rate, chloride concentration at different depths of the specimens and time necessary to initiate corrosion. It was planned to measure the threshold limit on which the corrosion turned from initiation period.
to propagation period. The results show that it is difficult to find a unique number as a threshold level and the values obtained are quite higher than those mentioned in other publications.

In-situ Characterization of Reclaimed Sandfill with Particular Reference to Dynamic Compaction
Principal Investigator: Na Yung Mook
Report No: CEE/PhD/2003/69

In order to characterize reclaimed sand, an extensive test programme was implemented comprising laboratory tests and in-situ tests including cone penetration test, self-boring pressuremeter test, cone pressuremeter test, dilatometer test, seismic cone penetration test, plate load test and in-situ density test. The validity of existing interpretation methods for the in-situ tests on the basis of density, shear strength, deformation modulus relationships and relative density as revealed by available field data from the site, were evaluated. The existing interpretation methods for in-situ tests were improved for use in the sandfill in Changi, which are of great importance for proper characterization and determination of geotechnical parameters of reclaimed sandfill. Reliable empirical correlations between qc and in-situ soil parameters based on reference parameter values obtained from the other in-situ tests and laboratory tests were established for the local application. The reclaimed sandfill was characterized and the change in soil parameters before and after dynamic compaction was assessed using the improved interpretation methods. An analytical model was developed that is suitable for describing the mechanism of the dynamic compaction through site measurements carried out during experimental full-scale tests. A plausible constitutive model for semi-infinite truncated cone model was selected to approximate this stress-strain relationship in a numerical analysis. The densification effect on sandfill as reflected in selected in-situ tests from dynamic compaction on the basis of the developed model was evaluated.

Structural Performance Monitoring and Health Assessment of Highway Bridges
Principal Investigator: Pilate Moyo
Report No: CEE/PhD/2003/70

The research work was divided into three parts falling under the broad subjects of structural health monitoring and condition assessment. The first part was concerned with detection of anomalies from structural health monitoring data and assessment of the effect of these events on structural behaviour. A procedure based on wavelet analysis was proposed for anomaly detection and Box-Jenkins models were proposed for assessing the impact of anomalies on structural behaviour. The second part dealt with instrumented condition assessment of bridges where a bridge is instrumented for a short period of time and probabilistic methods are used to model bridge specific live loading. In particular, the Type I extreme value distribution (Gumbel distribution) was adopted for modeling bridge live loads. Integrating this approach with modal analysis and model updating techniques would provide a useful basis for bridge assessment. The last part of the research was on the evaluation of fibre Bragg grating sensors and design of installation procedures for these sensors on civil structures. Fiber Bragg grating sensors (FBG) are offering a viable alternative sensing approach with some advantages over traditional sensors which include immunity to electromagnetic interference, light weight, multiplexing capabilities and corrosion resistance.

Response Of a Layered Random Soil Site Subjected to Earthquake Excitation
Principal Investigator: Wang Sheng
Report No: CEE/PhD/2003/71

The effects of random variations of soil properties and ground water level on soil site amplifications of seismic waves, or soil site responses are systematically studied in this study. The bedrock motions corresponding to the proposed earthquake scenarios are stochastically simulated and used as input to the soil site with SH wave or combined P and SV waves assumptions. Based on plane wave propagation method, random field theory and Rosenbluth method, computer programs are developed to estimate the acceleration time-history, the amplification spectrum, and the response spectrum of ground motion on surface of the random soil site. It is found that the incident motion is greatly amplified depending on incoming wave properties and site characteristics. Compared with the motion on surface of the soil site based on deterministic assumption, when random variations of soil properties and ground water level are included, the resulting ground motion on surface might have higher amplitude and wider frequency contents. The responses of soil sites in Singapore subjected to an earthquake of magnitude 9.0 occurred 550km away in Sumatra area are studied as an application. The effects of various local geological conditions in Singapore on site amplifications are analyzed by estimating typical soil sites random responses to the simulated bedrock motion. Results indicate that surface ground motions might be substantially underestimated if the random soil site characteristics are not considered in the calculation. The responses of RC frame structures to the estimated maximum credible ground motions on the typical soil sites are also investigated. Numerical results indicate that although such a large earthquake is unlikely to cause much damage to low- and mid-rise RC frame structures, it will cause severe damage to high-rise RC structures in Singapore if they are located on deep soil sites.

Predictive Instantaneous States Control of Elastic and Inelastic Structures during Earthquakes
Principal Investigator: Yang Rang
Report No: CEE/PhD/2003/72

The objective of this research is to develop a control algorithm called Predictive instantaneous states control (PISC) to meet some practical requirements in earthquake engineering, i.e., time delay compensation, discrete-time nature and ability to deal with inelastic structures. The idea of “predictive” refers to the method by which PISC compensates time delays. In PISC, the ideal control forces without considering time delays are first obtained. Time delays are then compensated by predicting the structural states over a period equal to the time delays and substituting these predicted states in the expression of the ideal control forces. The idea of “instantaneous” means that this algorithm is of discrete-time nature in the derivation where the discrete form of controlled structural systems is established. The law that the control forces follow is optimized by minimizing an instantaneous performance index at every step. The idea of “states” implies that the aim of this algorithm is to control the structural states, that is, displacements and velocities. “Elastic and inelastic structures” means that PISC is applied to both elastic and inelastic structures. Force analogy method is used as the inelastic analysis method. Finally, “during earthquake” means that earthquake is the external excitation force in this study. PISC is studied in terms of both specific structure and response spectra. Three parameters affecting the control performance, that is, the weighting matrices, the magnitude of time delays and the structural natural period, are discussed in detail using numerical simulations. Results show that PISC compensates the negative effects of time delays greatly. The study in spectra shows that PISC has best control
performance on structures having periods between 1.5 second to 3.5 second and it can be applied for different earthquakes. Inelastic structures with post-yield characteristics of elastic-plastic, strain-hardening and strain-softening are included. Finally, PISC is applied to a practical MDOF structure to demonstrate its effectiveness on MDOF structures and its design procedure.

**Behaviour of Reinforced Concrete Beam-Column Joints under Cyclic Loading**

*Principal Investigator: Zhou Hua*

*Report No: CEE/PhD/2003/73*

This research is intended to investigate the behaviour of reinforced concrete beam- column joints under cyclic loading. It consists of three parts. One part is experimental study on interior eccentric joints, the second part is parametric study on interior and exterior joints, and the last part is numerical analysis of the effect of bond deterioration on the behaviour of interior joints. The essential point of the findings is that the maximum joint shear stresses of joint specimens may not be a good indicator of joint shear strength, since they are found to change closely with changing joint shear inputs. It is suggested that joint shear strength be determined by limiting joint shear deformation to a reasonable level. The information obtained from this research is believed to be useful for clarifying the conflicting viewpoints on the behaviour of beam-column joints under cyclic loading.

**Numerical Analysis of Reinforced Concrete Using Multi-Surface Strength Model**

*Principal Investigator: Zhou Xiaoqing*

*Report No: CEE/PhD/2003/74*

In the present study, a plastic damage material model for concrete has been developed. The stress states in the present model are defined with respect to four progressive strengths: surfaces, i.e., the initial yield surface, loading surface, failure surface and residual strength surface. Two versions of the constitutive model are developed, namely the static version and the dynamic version. The differences between the two versions lie in the definition of the failure surface and the post-failure treatments. In the dynamic version, the strain-rate effect is included in defining the failure surface. In addition, the post-failure behaviour follows a kind of isotropic damage model, in which the damage scale is a measure of the accumulated equivalent plain strain. Of course in the static version, no strain-rate effect is considered, and the post-failure treatment adopts the Mazars’ damage model, in which the damage parameter is a measure in the direction of principle stress. The validity of the present multi-surface strength models is illustrated through comparisons with available experimental results. For the static cases, verification of the accuracy is through an investigation of reinforced concrete beams under static loading. For the dynamic cases, it is illustrated through concrete slabs against perforation by high-speed hard projectile. Comparisons of the results show that the present static and the dynamic constitutive models for concrete yield good prediction of the complicated phenomena.