**Anaerobic Digestion of Strong Wastes**  
*Principal Investigator: Jeyaseelan, S*  
*Report No: CEE/2001/87*

Numerous studies have been conducted in an attempt to identify the factors affecting performance of anaerobic packed-bed reactors. However, the effects of media characteristics on reactor performance have not been explored in much detail. This study examined the significance of media specific surface, porosity, pore size, and surface texture on treatment performance of the laboratory scale anaerobic packed-bed system. The role and significance of entrapped suspended biomass with respect to the media parameters have also been investigated. The performance of these systems were compared with the two-phase system operating a continuously stirred completely mixed reactor as acid tank (first phase) and a packed-bed reactor as methane reactor (second phase) has been used to investigate the performance compared single stage systems. Four laboratory scale anaerobic packed-bed reactors were designed and operated to treat a soluble synthetic protein-carbohydrate waste. All reactors were operated simultaneously at the same hydraulic and organic loading rates, with the only difference among these reactors being the medium used to support biological growth. Biogas production, methane content, chemical oxygen demand (COD) removal, total volatile acids, biomass concentrations, and specific methanogenic activity were determined under steady-state conditions at various organic loadings. The results from different reactors were compared to assess the effects of media characteristics on process performance. The laboratory results obtained imply that media pore size and porosity are more important criteria then specific surfaces area in the selection of support media. Media surface texture is also an important selection factor for biomass adhesion. It is suggested, therefore, that media of high porosity, large pore size as well as open-pore surface texture should be used in upflow anaerobic packed-bed systems. For all the loading conditions tested, two-phase operations show better COD removal efficiencies and gas production rates. Also the methane contents in the gas produced by two-phase operations are more in all the operations compared to the corresponding single phase operations. Both processes have better removal efficiencies than conventional treatment processes.

**Erosion Below Tidal Sluice Gate**  
*Principal Investigator: Lim Siow Yong*  
*Report No: CEE/2001/88*

This report presents the results of an extensive experimental study on the hydraulics and local scour phenomenon caused by high velocity jets issuing from submerged sluice gates or two-dimensional jet outlets. The main objective was to study the extent of the erosion of the riverbed downstream of the structure. 84 sets of experiments covering a wide range of jet velocities, apron lengths and sediment sizes have been conducted. Dimensional analysis was used to delineate the characteristic parameters affecting the maximum scour depth downstream of the structure. Under certain hydraulic conditions, the study discovered a jet-flipping phenomenon whereby the jet action would flip from the bed to the water surface and vice versa. The process is cyclical and is dependent on the depth of the scour hole and the relative proximity of the bed and free surface to the jet axis. On the scour hole characteristics, the results show that the time development of the centerline scour profiles was self-similar. The erosion at the interface between the solid apron and the sand bed, i.e., at the brink of the apron was also measured. The reverse flow in the toe region immediately downstream of the apron causes this to occur. The maximum brink scour depth was found to be about 0.44 times the maximum scour depth. For the latter, a predictive formula has been proposed based on a database of 163 experiments from the present study and various other researchers. The maximum scour formula takes into account the jet size and velocity, median sediment size, sediment density and gradation and the length of the protective apron. The range of applicability of the formula, and its uses and limitations are discussed. The formula was used to estimate the maximum scour caused by the high jet velocity issuing from the sluice gate of the Shimen Arch Dam in China and the prediction was close to the measured scour in the field.

**Structural Behaviour of Completely Overlapped Tubular Joints**  
*Principal Investigator: Soh Chee Kiong*  
*Report No: CEE/2001/89*

The recommendations for the design of completely overlapped tubular joints are insufficiently covered in the existing design codes and guides. Besides, background information is also not available. However, this joint configuration could provide easy fabrication and could have better static strength than the simple gap joints. In addition, cost savings in term of materials and construction man-hours can also be realised. So far, due to its geometry, the completely overlapped joint is commonly misinterpreted as two separate T/Y-joints. Thus, the stiffening effect of the weld and the chord wall, which restrain the through brace from ovalisation, is omitted. This is bad practice as small gap exists between the outer surfaces of the chord and the lap brace on the through brace surface, resulting in the shell membrane and bending stresses to have significant effect on the load interaction among the members at the connection. In this study, the behaviour of completely overlapped joints is studied both experimentally and numerically. The results showed that the joint demonstrated good ductility performance with ultimate capacity close to that of the gap K-joint. The existing T/Y-joint formulae considerably underestimated the stress concentration factors on the through brace saddle near the chord, and overestimated the stress concentration factors on the lap brace. The local joint flexibility was also found to be underestimated. Overall, the completely overlapped joint has shown higher ultimate capacity, better fatigue performance and smaller elastic deformation in comparison to the simple T/Y-joint. It is therefore concluded that the concept of using the completely overlapped joints in the offshore construction industry is promising, with great potential for actual application.

**Conversion of Municipal Sewage Sludge to Activated Carbon**  
*Principal Investigator: Jeyaseelan, S*  
*Report No: CEE/2001/90*

Disposal of sewage sludge is an increasingly expensive and
environmentally sensitive problem throughout the world. Preparation of carbonaceous adsorbents from sewage sludge offers an attractive re-use alternative to the traditional disposal routes. In this research, carbonisation and chemical activation with ZnCl₂ were employed to prepare carbonaceous 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. Surface area, pore size distribution, aqueous phenol adsorption capacity and the production yield of the adsorbents produced under each condition were assessed. For all the adsorbents produced from the mixtures of sewage sludge with coconut husk and peanut shell, the production yields were higher than 35% regardless of preparation conditions. Resulting from the preparation studies, the optimum preparation conditions were obtained to produce adsorbents from the sewage sludge and the mixtures. These adsorbents were all of meso- and micro-porous character and had well developed porosity with BET surface area over 490 m²/g and up to 882.3 m²/g. They were acidic in nature with the quantities of about 0.5. Below the threshold value, no significant winnowing process is active.

Armouring and Rip-Rap Protection
Principal Investigator: Chin Chen On
Report No: CEE/2002/91

Armouring of streambed may occur naturally in rivers or streams by the selective erosion of sediments with non-uniform particle size distribution or artificially, by placing a coarser layer of particles on top of a bed of finer particles manually as a form of ripraps. In river flows, there exists a process of selective erosion where small particles among the interstices of larger particles are “sucked” or “winnowed” out by the hydrodynamic forces and being carried into the flow. This leaves behind a layer of heavier and larger particles to act as the protective armor coat. This process is known as “winnowing”. This project experimentally examines the mechanism of winnowing and the stability of ripraps. Different particle size ratios (d₁/d₂) and flow conditions (Uᵢ/Uᵦ) are investigated in terms of a bed degradation process. The flows are set within the range of 0.4 < Uᵢ/Uᵦ < 0.9. For Uᵢ/Uᵦ > 0.9, the protective layer becomes unstable and breaks up after a period of time caused by the progressive entrainment of the coarser particles. A dimensional analysis of parameters was used to guide the experiments. Observation of the experiments shows that the process of winnowing is a substitution process. The preferential entrainment of the finer particles enables the larger particles to adjust their exposure to the flow that tends to even out the local strengths and weaknesses of the protective layer. In this way, the armour remains intact without breaking up for flows near the critical condition the coarser particles. No significant winnowing occurs when Uᵢ/Uᵦ is less than 0.5. The rate of winnowing increases rapidly with Uᵢ/Uᵦ and d₁/d₂ ratios. An increase in Uᵢ/Uᵦ value means that the intensity of turbulence increases which enables greater amount of smaller particles to be winnowed out. An increase in d₁/d₂ value means that the interstices are larger and finer particles are more exposed to the flow. The threshold of winnowing decreases with d₁/d₂ ratio reaches a minimum value of about 0.5. Below the threshold value, no significant winnowing process is active.

Assessment of Dynamic Ground Motions in Singapore
Principal Investigator: Pan Tso Chien
Report No: CEE/2002/92

Tremors originating from Sumatran earthquakes have frequently been felt in Singapore in recent decades. The Singapore Array for Earthquake Response (SAFER array) was established in 1996 to gain insights into the characteristics of earthquake ground motions in Singapore. This array consists of seven seismics stations under the Meteorological Service Singapore (MSS) seismic network and three seismic stations under the Nanyang Technological University (NTU) seismic network. Between 1996 and 2000, the largest peak ground acceleration (PGA) recorded at the rock outcrop site in Singapore is about 0.4 gal. The PGA at the Katong Park (KAP) soft soil site is about four to five times the largest PGA recorded at the rock outcrop site. The three recent Sumatra events occurred on 1996-10-10, 1998-04-01 and 2000-06-04 have a large response at frequencies below 0.2 Hz at all the seismic stations. The low frequency component was shown to dominate in these far-field earthquake ground motions. The response spectra at rock outcrop site, the Bukit Timah Diary Farm (BTDF) site, had a flat response during these events. The Fruit Tree Centre (FTC) site, a stiff soil site, showed response spectra with characteristics similar to those of BTDF. The response spectra at the other soil sites showed peak values at frequencies corresponding to their respective site frequencies. The site frequencies were found to be about 3 Hz at the NTU site of residual soils. For soft soil sites, the site frequencies were 1 Hz at the Beatty Secondary School (BES) site and 0.7 Hz at the KAP site.

The Effect of Principal Stress Rotation on the Strength and Deformation Behaviour of Singapore Soils
Principal Investigator: Chu Jian
Report No: CEE/2002/93

It is well known that the rotation of principal stresses affects the strength and deformation behaviour of soils considerably. However, studies on the effect of principal stress rotation are very limited due to the complexity involved in the experiments. The objectives of this project were to develop a hollow cylinder apparatus (HCA) and to use it to study the anisotropic stress-strain, in particular, the instability behaviour of a granular fill material under general stress conditions including principal stress rotation. A literature review was conducted to summarise the latest development in the testing techniques and the research work on the effect of principal stress rotation. A triaxial compression/extension testing system and the developed HCA were described. The stress and local strain measuring devices used in the triaxial and HCA tests are elaborated. The sample preparation methods adopted for triaxial and HCA tests were
discussed. Test results obtained from both triaxial and HCA tests were conducted and the test results were presented. Comparisons between the stress-strain behaviour of the granular fill material obtained from triaxial tests with compression/extension loading and that from HCA tests with different angles of rotation were made. Based on the triaxial testing results, it was established that the critical state line for triaxial compression tests is different from that for triaxial extension tests. Instability can occur for loose sand in triaxial extension tests under either drained or undrained conditions. It was also observed that the total stress paths used in conducting CK,UE tests affects the undrained behaviour of loose sand. The HCA testing data indicate that some excess pore water pressures are generated when there is a rotation in the principal stress direction under undrained conditions. The mobilised angle of shearing resistance at the phase transformation state, $\varphi_{PT}$, changes with the angle of principal stress rotation. The $\varphi_{PT}$ obtained from the HCA tests at $\alpha$ equals to 0 and 90° are higher than that obtained from the triaxial compression and extension tests under the respectively conditions. As the HCA tests were conducted with a b value of 0.5 and the triaxial tests with b values of 0 for compression and 1 for extension tests, the difference reflects the effect of the intermediate principal stress. Shear bands were normally formed at the end of a HCA test except in the test with $\alpha$ of 0 degree, where the specimen bulged as what would be observed from a triaxial test on loose sand.

**RP 31/95 Design of Reinforcement in Concrete Slabs – Phase 1**

*Principal Investigator:* Lee Sai Cheng  

This report investigates the punching resistance near the interior column regions of flat plate. The experimental work involved testing of twenty-eight isolated slab-column specimens cast using normal strength concrete (NSC) and high strength concrete (HSC). The parameters in the tests included column rectangularity, types of shear reinforcement and the grade of concrete. The NSC slabs were supported by rectangular columns of different length to width ratios of 1, 3 and 5. These specimens contained shear reinforcement in the form of double-leg stirrups, single-leg C-stirrups and stud shear reinforcement. The results showed that the stud shear reinforcement with an enlarged head at each end is the most efficient device for improving the punching strength and ductility of thin slabs. It enhanced the punching shear strength of 200mm slabs by 43 to 78% compared to a similar slab without shear reinforcement. The double-leg stirrups and C-stirrups were less efficient due to improper anchorage. The increased in shear resistance were 12 to 40% with double-leg stirrups and 14 to 46% with C-stirrups. The shear stress distribution round the rectangular columns was non-uniform; it was high at the corners and the short sides of the rectangle and low at the long sides of the rectangle. Express in terms of average shear stress at 0.5d from the column face, the punching capacity dropped by 18 to 25% around the 250 × 750 column section and 24 to 41% for the 250 × 1250 column section. The HSC slabs were cast using grade 80 concrete to investigate the effectiveness of C-stirrups in enhancing shear. When 0.5% to 1.1% of C-stirrups were used, the punching strengths of HSC slabs were increased by 31 to 54%. The strain measurements indicate the efficiency factors of stirrups is respectively 65% and 70% for the 200mm and 275mm slabs.

**Strength Improvement of Peaty Soils**

*Principal Investigator:* Leong Eng Choon  
*Report No:* CEE/2002/95

In Singapore, there are generally two deposits of peaty soils lain at different geological times. The younger peaty soil deposit found close to the ground surface is the subject of this study. The Singapore peaty soils have not been well researched. The younger peaty soil when encountered in construction is usually disposed at landfill sites. Considering the limited landfill capacity and small land area of Singapore, it is more attractive to improve the properties of these peaty soils. Soil improvement methods can be classified into temporary techniques that are limited to the period of construction, permanent techniques with the addition of materials and permanent techniques which preclude the addition of other materials into the soil. This study looks into the latter two groups. Preloading by mechanical surcharging and vacuum preloading and the addition of chemical admixtures of cement, lime and municipal solid waste fly ash or MFA were investigated. The peaty soils had organic contents of 10 to 30%. Their compressibility increases with increasing organic content. Vacuum preloading appeared to be more effective than mechanical surcharging at equivalent normal stress levels up to the point when the soil starts to desaturate. The addition of cement, lime and MFA to peaty soil changed the physical, chemical and engineering properties of the peaty soil. Shear strength of the peaty soil was improved with the addition of cement, lime or MFA. Cement was a more effective admixture than lime or MFA at equivalent calcium oxide contents. The strength gain of the soil mixtures with cement was more rapid than with either lime or MFA. The environmental impact on the utilisation of MFA as an admixture for the peaty soil was investigated through leaching tests. The heavy metals concentration in the leachate from the leaching tests was found to be lower than the regulatory levels.

**Development of an instrument for Field Measurement of Suction in Unsaturated Soil**

*Principal Investigator:* Leong Eng Choon  
*Report No:* CEE/2002/96

Unsaturated soils whose pore-water pressures are negative are encountered in many geotechnical engineering problems. To understand the behaviour of unsaturated soils, measurement of negative pore-water pressure or soil suction is a pre-requisite. This project aims to develop a field suction measuring device. A number of devices are available commercially for soil suction measurement. These suction measuring devices can be further improved as they suffer from problems such as long equilibration time, limited suction range, hysteresis, poor sensitivity, or equipment deterioration. After evaluating a number of suction measuring instruments, three types of suction measuring devices were developed in this project. Development includes the ancillaries of the devices. The thermal conductivity sensor is promising as a long term matric suction measuring device in the field. Improvements need to be made in terms of the porous material of the thermal conductivity sensor and the electronics. This project had concentrated on the ancillaries of the thermal conductivity sensor which includes the power supply to the thermal conductivity sensor and the data acquisition system. The calibration and data interpretation of the thermal conductivity sensor are important aspects that should have warranted more attention prior to its usage. A high-suction tensiometer for matric suction measurement has been developed which does not suffer from the problems that have been reported in the literature. Further
improvement to its design and ancillaries can be made to enhance its performance in the field. The other device developed incorporates a relative humidity sensor and measures total suction. The device was found to give lower total suction readings when compared with independent measurement of matric and osmotic suctions. It is suggested that with calibration, the device readings can be corrected to reflect a reading closer to the actual total suction.

**Improving the Design of Bored and Cast-in-Place Piles in Residual Soils and Weathered Rocks**

*Principal Investigator: Chang Ming-Fang*

*Report No: CEE/2002/97*

Bored and cast-in-place piles, or bored piles, are widely used in tropical regions since they are well-suited for the support of heavy structures resting on residual soils and weathered rocks. Local practice for the design of bored piles in residual soils is inadequate in that there are insufficient considerations of detailed load transfer along the piles and construction effect. This research focused on the effect of construction effect on the load transfer behaviour along bored piles in the residual soil of the Jurong Formation in Singapore. Extensive laboratory and in-situ tests were carried out to characterize the residual soil and to investigate the construction effect on the soil properties, particularly from soaking. Results indicate that the shear strength and the deformational properties of the residual soil deteriorate with soaking. The change in moisture content in the soil is highly dependent on the liquidity index of the soil and the water/cement ratio of the concrete. Pull-out tests carried out on miniature bored piles in the field indicate that the reduction in ultimate shaft resistance is about 5-10% after the boreholes were soaked for 0.5-2 hours. The amount of reduction increases to 20% when the boreholes were subjected to soaking of over two hours. To model the construction effect, different construction procedures were simulated carefully using the finite element method. The numerical analysis shows that, after construction, the horizontal stress does not return to its original state. This observation has been verified through a field measurement of horizontal stress in the soil adjacent to a bored pile during construction. A procedure that accounts for the nonlinear decrease of modulus with an increase in strain level and for the construction effects in the analysis of load transfer along a bored pile has been developed and the predicted load transfer curves have been found to compare well with those back-calculated from load tests of instrumented bored piles in Jurong Formation.

**Traffic Characteristics and Interactions at Signalised Junctions**

*Principal Investigator: Lum Kit Meng*

*Report No: CEE/2002/98*

A number of field studies had highlighted various limitations associated with using video cameras for traffic studies at signalised junctions. A data logging system comprising a customised logger and dedicated loop sensors was thus conceptualised and developed for gathering traffic and crossing/stoppage movements of vehicles during the signal change interval. The logging system was used to evaluate the effect of Red Light Camera (RLC) at a number of sites through a before-and-after study and a treatment-versus-comparison study. In the before-and-after experimental design, RLC was found to have a strong influence in suppressing red-running along the camera approaches, but its effect varied with traffic conditions. At less congested and high-speed junctions, the effect of RLC on the stopping propensity is moderated by interaction between distance and speed factors. At congested and lower speed junctions, no interaction effect was apparent and an odds ratio of about 8.5 times likelihood of stopping was observed in the after-RLC situation. Under the treatment-versus-comparison design, the RLC exerted significant effect and no significant interaction was evident. The odds ratio to stop at camera approaches was about 17 times higher than at non-camera approaches. The red running violation rates were substantially reduced by an average of about 40% across the camera approaches in the after-RLC situation. The change in violation rates at non-camera approaches was not conclusive. As for the sites under the treatment-versus-comparison design, the non-camera approaches of the camera and non-camera junctions had respective violation rates of about, on average, 2.4 and 4.2 times higher than at camera approaches. These findings were consistent and in agreement with those obtained at the before-and-after junctions. This study has provided useful guidelines to evaluate junctions for RLC installation as well as to improve on the implementation and operational aspects of the RLC programme.

**Bouyant Jet Discharges in Coastal Waters**

*Principal Investigator: Adrian Law Wing Keung*

*Report No: CEE/2002/99*

Environmental impact assessment is an essential step in the design analysis of discharging industrial and sewerage effluent to the sea. The assessment normally requires quantifying the mixing between the discharges and neighbouring coastal waters by relationships developed in past laboratory studies. Due to experimental limitations, these studies typically adopted intrusive methods for the measurements which introduce uncertainties due to the disturbance of the flow itself. In this project, a laboratory approach is developed based on advanced laser imaging. The approach combines the Particle Image Velocimetry (PIV) and Planar Laser Induced Fluorescence (PLIF) techniques to determine in a non-intrusive manner the synchronised planar flow velocities and concentrations in a study area. The data density is very high as more than a thousand velocity vectors and a million concentration pixels can be collected for the area. Various considerations for this combination are investigated, including the potential interference effect between the seeding particles for PIV and the fluorescent dye excitation for PLIF. Using the combined laser imaging techniques, the mean and turbulent properties of vertical round jets, plumes and buoyant jets are examined thoroughly including the transition from buoyant jet to plume. A refined integral model is then developed based on the experimental findings that achieve a second-order conservation of mass and momentum fluxes. This model produces enhanced prediction as both the mass and momentum fluxes contributed by turbulence are accounted for properly.
2D Cracks Analysis with Symmetric Galerkin Boundary Element Method  
**Principal Investigator:** Xu Kai  
**Report No:** CEE/PhD/2002/ 42

The practical applications of a Symmetric Galerkin Boundary Element Method (SGBEM) for multiple traction-free cracks, frictional contact and cohesive cracks problems are described in this thesis. Attention has been concentrated in deriving the formulations used for the analysis of these problems. For the analysis of 2D linear elastic crack problems, the proposed approach can easily deal with any number of traction-free cracks within a single domain formulation. To further demonstrate the effectiveness of a single domain SGBEM for crack problems, a non-load-carrying and a load-carrying transverse fillet welded joints containing an edge and two embedded cracks, were analyzed for a range of geometries. In the numerical implementation, a two-stage interpolation method called the “Quasi-Higher Order Element Method” (QHOEM) was then proposed to solve for the integrals. The sub-domain SGBEM was applied to a number of angle crack problems involving crack surfaces in contact. The incremental iteration technique was used in the analysis. Stress intensity factor solutions are presented for a range of geometries and coefficients of friction in each of the problem. A fully symmetric Galerkin boundary element method sub-domain technique was then extended for the cohesive crack model. During the fracture process, the crack was simulated by means of the cohesive crack model (CCM).

A Study of Concession Design and Risk-Return Trade-Offs For Privately-Financed Infrastructure Projects  
**Principal Investigator:** Ye Sudong  
**Report No:** CEE/PhD/2002/ 43

Compared with traditional construction (design-bid-build) projects, the risk exposures of the promotors in privately-financed infrastructure projects are high because of the extended responsibilities of raising the finance as well as building the project and operating it over a long time. The central concern of the project promoter will be the concession design. This research investigated key aspects of concession design based on the concept of risk-return trade-offs. Its first hypothesis is that the decision to invest in infrastructure projects largely depends on the trade-offs between risk and return, and that appropriate trade-offs between risk and return can be achieved through the design of contractual arrangements, financial structure, and government support. Then the analysis in this research concentrated on the design of contractual arrangements, financial structures, and government support at strategic level, and the design of concession period structures, the tariff structures of concession design, and tariff regulation at operational level. To design an appropriate concession arrangement, the risk exposures of a project as well as its profitability should first be understood. In this research, a computer simulation model to assess the viability of the project, as well as the NPV-at-risk method for measuring the effectiveness of alternative designs was developed. Then in-depth analyses of seven selected cases were carried out to analyse the concession design in practice.

Consolidation of Soft Clay using Vertical Drains  
**Principal Investigator:** Xiao Daping  
**Report No:** CEE/PhD/2001/ 44

Both experimental and numerical studies were carried out to pursue a better understanding of the consolidation behaviour of soft clay with vertical drains. Two series of large-scale model tests were conducted using a consolidometer of 1.0 m in diameter. The first series of tests focused on the evaluation of smear zone. Based on the test results obtained, the extent of the smear zone was found to be equal to four times the radius of the mandrel, and the average horizontal permeability in the smear zone was 1.3 times smaller than that in the intact zone. In the second series of tests, the effects of smear and well resistance on consolidation behaviour were studied by large-scale “unit cell” modeling conducted under contrastive “smear” and/or “well resistance” conditions. Finite element elastoplastic analyses were performed to provide more insights into the vertical drain problem and extend the experimental findings to more general applications.

Condition Assessment of Structures Using Dynamic Data  
**Principal Investigator:** Xia Yong  
**Report No:** CEE/PhD/2002/ 45

Structural condition assessment is a critical problem worldwide because the structural failure could be catastrophic in terms of the loss in economy and life. Vibration-based methods have been widely applied to identify structural damage, throughout the civil, mechanical and aerospace engineering communities during the past few decades. There are three contributions from this study, namely, deterministic damage identification, probabilistic damage identification and measurement selection algorithm. First, the initial structural finite element (FE) model and measured modal data are assumed accurate in damage identification. A real-coded Genetic Algorithm was applied to search the global optimum solution in model updating so that the model predictions match the measured data in an optimal way. Then the uncertainties existing in the FE model and measured vibration data were considered as random variables with certain distribution, the probabilities of damage occurrence of structural members are estimated. Finally, a new method was developed to derive a proper set of measurement points to be used in structural damage identification by combining the damage sensitivity and noise sensitivity together. Numerical and experimental results show that the proposed algorithms can improve the damage identification results.

Condition Assessment of Bridges by Dynamic Measurements and Finite Element Model Updating  
**Principal Investigator:** Xia Pin Qi  
**Report No:** CEE/PhD/2002/ 46

The use of traditional methods such as cable-stayed bridges and suspension bridges has not been too successful in condition
This research presents a new methodology for quantitative condition assessment of bridges using dynamic measurements and sensitivity-based finite element (FE) model updating. Compared with traditional methods, the new methodology is very practical for quantitative assessment of bridge condition. In a study of cable stayed bridge, the bridge dynamic properties were improved to agree well with the prototype testing data. In a study of a model bridge, by setting up the ‘damaged’ FE model, the degree of damage of a severely damaged structure was assessed. In a study of a model reinforced concrete (RC) bridge, the residual stiffness of the RC structure at failure was determined. Based on this test study, a practical approach for estimation of load-carrying capacity of a damaged RC beam bridge was presented. The accuracy analysis of the damage assessment in a controlled study verified the reliability of condition assessment using the methodology. The reliability of updated structural parameters was demonstrated using Monte Carlo simulations on the effect of data noise on modal parameters.

**Fuzzy Dynamic Damage Analysis of Rock Mass**

*Principal Investigator: Wu Chengqing*

*Report No: CEE/PhD/2002/47*

A rock mass contains naturally occurring network of flaws, joints and planes of weakness. Due to the randomness of the distributions of flaws and joints in space, their sizes and orientations, the material characteristics of the rock mass are of statistical nature. The present study analyzes the statistical properties of the Bukit Timah granite in Singapore and derives their probabilistic distributions based on the measured data from field and laboratory tests. These statistical properties are incorporated into the constitutive law and cumulative damage model for a rock mass. Using fuzzy probabilistic theory, an isotropic damage model with stochastic approach was used to analyze the responses and fuzzy failure probability of the rock mass subjected to blasting loads. In order to achieve a more accurate estimation, anisotropic damage models with equivalent material properly approach and stochastic approach are also proposed to estimate the dynamic response and fuzzy failure probability of the rock mass under explosion loads. These suggested models are programmed and linked to an available computer program Autodyn through its user’s subroutines. Using the Autodyn programme together with the suggested random and fuzzy probability model, a series of fields blasting tests are simulated. Stress wave propagation and damage zone in the rock mass; due to underground explosion are calculated. Numerical results of stress wave attenuation, propagation, and wave forms, are compared with field recorded data. Using the numerical model, parametric studies have been carried out to investigate the effects of various blasting conditions on stress wave propagation. Some empirical formulae, which include the effects of different conditions to predict stress wave intensities and principal frequency, have been derived.

**Behaviour of Reinforced Concrete Elements Strengthened with FRP Plates**

*Principal Investigator: Nguyen Dai Minh*

*Report No: CEE/PhD/2001/49*

This thesis is concerned with the behaviour of concrete beams strengthened with carbon fibre reinforced plastic (CFRP) plates. The objective of the research was to characterise the brittle failure modes of concrete ripping-off and delamination of the CFRP plate. Formulae to determine the required CFRP plate size were proposed for the flexural analysis. An improved analytical solution to predict stress-concentration in the adhesive layer at the plate-termination region was recommended. Results obtained using this method compared well with published results. Tests of 33 concrete beams bonded with CFRP plates were conducted. A composite model was proposed in combination with strain-limiting criteria to predict the concrete ripping-off. The results obtained using the developed formulation showed good agreement with the experimental results. Delamination of CFRP plate was also discussed. This failure mode could be avoided by limiting the maximum plate strain to a recommended value. Finally, design guidelines for concrete beams strengthened with CFRP plates were proposed.

**Impact of Red Light Cameras on Traffic Characteristics and Interactions at Signalled Junctions**

*Principal Investigator: Lum Kit Meng*

*Report No: CEE/PhD/2002/50*

A customised data logger working in conjunction with inductance loop sensors was conceptualised and set up for traffic data collection at signalized junctions. The propensity of stopping at the onset of amber was investigated by logistic modelling for both the before-and-after and treatment-and-comparison studies. The results indicate that the effect of red
light camera (RLC) on the decision-making of drivers is confirmed only to the camera approach, and it interacts significantly with distance for less congested and high-speed junctions. About 40% reduction in red violation rates along the camera approach was observed after RLC installation. No noticeable effects on amber crossing were observed, while the red stopping rates were increased by 5 to 10 times along the camera approach. RLC can reduce the probability of right-angle collisions ranging from 2% to 9%, with higher reductions at junctions with lower all-red timings. The findings have provided a number of objective measures to evaluate the operational aspects of RLC program.

Mathematical Programming Approach to Elasto-plastic Structural Analysis
Principal Investigator: Li Xuyang
Report No: CEE/PhD/2002/51

This research focuses on mathematical programming (MP) applications in elasto-plastic structural analyses, mainly for structures of frames and submarine pipelines. A distributed plastic model based on the flexibility approach was developed and applied to analyzing structures which could be discretized into beam elements. For complicated multi-bay multi-story frames, an improved flexibility approach was developed; thus the computing can be conducted automatically without manual intervention. The holonomic elasto-plastic analysis of submarine pipelines is a coupled nonlinear problem and can be cast into a linear complementary problem (LCP) which can be solved by highly efficient MP algorithms. For historical analysis of submarine pipelines, which is nonholonomic, incremental approach has to be applied to derive a parametric linear complementary problem (PLCP) which actually consists of a series of LCPs. Based on mathematical recurrence computing, an improved PLCP algorithm is proposed, which can be applied to all PLCP.

Effect Of Membrane Charge On Nanofiltration
Principal Investigator: Liu Jianlin
Report No: CEE/PhD/2001/52

Although promising in water treatment, nanofiltration suffers from major problems such as membrane fouling and low rejection of small particles. This dissertation presents the investigation on the effect of membrane charge on nanofiltration. The objective was to look into the electrokinetic phenomenon in order to improve the filtration performance and reduce membrane fouling. A membrane surface charge model was established by correlating the membrane surface charge density to the solution physicochemistry. Based on the model, the effect of membrane charge property on the performance of nanofiltration and membrane fouling could be assessed. The ion rejection was demonstrated to follow the surface charge filtration model. The guidelines to achieve optimum operation conditions were proposed. Experimental results also showed that membrane fouling was strongly influenced by the membrane surface charge. New parameters of “fouling weight” and “fouling rate” were defined to characterise the quantity of foulant. In addition, the high-voltage electrostatic water treatment method was tested and the results were encouraging.

Parallel Processing For Transient Response of Large Buildings
Principal Investigator: Li Jing
Report No: CEE/PhD/2001/53

In the land-scarce Singapore, there is a constant need to make the best use of all available lands. As expected, industries that operate in a multi-storey environment are better able to achieve higher land productivity levels. This research was motivated by the need to calculate the vibration response in the factory floor area resulting from container trucks travelling within a large multi-storey factory building. The objective was, therefore, to develop a numerical technique that would solve this computational problem efficiently. The thesis consists of two main parts of study. They are the Dynamic Finite Element (FE) method for transient dynamic response of a coupled vehicle-structure system and the Parallel Algorithm for transient dynamic response of large structures. In this study, a precise dynamic FE approach is proposed to solve the transient dynamic response of a vehicle-structure interaction system in time domain. It considers the vehicle as a moving part of an entire system, i.e. to consider the vehicle influence at the element level. The advantage of this method is its unconditional stability while exploring the implicit direct time integration method and its capability to easily handle multi-vehicles with multi-axles without any approximation and iteration on the displacement compatibility and interaction force at contact points. At the same time, simplified methods have been studied for comparison. Four influence parameters, the road roughness, speed parameter, mass ratio and frequency ratio, have been studied for their effects on the response. Because of the complexity and periodicity of a typical multi-storey factory building, a parallel finite element algorithm for transient dynamic response analysis has been derived based on an unconventional partitioning method -the overlap fixed boundary domain decomposition method. The parallel algorithm is implemented via the master-slave approach. This algorithm does not need to form the complicated global equations of shared degrees of freedom need explicitly or implicitly. The whole process is fully parallel and well suited for implementation in a distributed memory system. The algorithm developed has a very good locality, and the iterative correction procedure on the shared boundary converges fast and needs only a small amount of message communication between the master and slave processes. The method has been developed in the least expensive parallel environment -a WIN32 PC cluster based on the PVM parallel environment. Numerical examples are included to demonstrate the accuracy and efficiency of the method developed. The large factory building with elevated access has been analysed via this parallel program. The comparison with sequential software is presented for accuracy, while the speed-up factors are obtained for the examples to demonstrate the efficiency of the proposed algorithm.

Soft Clay Consolidation Under Reclamation Fill and Reliability Analysis
Principal Investigator: Li Guoju
Report No: CEE/PhD/2001/54

The purpose of this study was to develop a method that can be used to predict the response of subsoil treated with vertical drains, study the effect of uncertainties of soil properties and spatial continuity on the settlement and rate of consolidation,
expand the application of reliability theory in geotechnical design, and develop a method to design the vertical drain spacing and surcharge pressure considering the uncertainties of soil properties. A computer program, VD2000, was developed to predict the settlement and excess pore pressure of the clay treated with vertical drains. The VD2000 used implicit finite difference method to solve the governing equation. Several factors are considered in VD2000. The in-situ performance of clay installed with vertical drains in a pilot test area measuring 294 m long and 251 m wide was studied. A modified response surface method was developed in this study to evaluate the failure probability for engineering problems. The proposed method can use any existing numerical software and spreadsheet software to evaluate the failure probability. Both the settlement and rate of consolidation were studied using the probability and reliability methods. Reliability based design was also studied. The design variables are the spacing of vertical drains and the surcharge pressure. The Changi site is used as an example to illustrate the concepts.

**Structural Behaviour of Completely Overlap Tubular Joints**

*Principal Investigator: Gho Wie Min*

*Report No: CEE/PhD/2001/ 55*

The behaviour of the completely overlap joints is not identical to that of the simple T/Y-joints. Only at a large gap, the joint behaves as a T/Y-joint. As the gap reduces, the ultimate capacity of the joint increases but the stress concentration and the local flexibility of the joint decrease. These indicate that the completely overlap joint has a higher ultimate capacity, a better fatigue performance and a smaller elastic deformation in comparison to the simple T/Y-joint. Additionally, the joints are easily fabricated and inspected. The use of the shorter thicker wall cans at the joint connections is possible as the number of braces joining the chord has reduced. The joint also demonstrates advantage in minimising the ground works and the fabrication man-hours during the construction stage of the jacket structure. From these findings, the concept of using the completely overlap joints in the construction of offshore jacket structures is promising and has great potential.

**Macro-updating of Finite Element Modeling for Core Systems of Tall Buildings**

*Principal Investigator: Deng Xueyuan*

*Report No: CEE/PhD/2002/ 56*

This study presents an attempt on finite element model updating with a knowledge-based system. After investigating knowledge and experiences of model updating techniques and finite element modeling of tall buildings, a knowledge-based system was developed to implement finite element model updating of tall buildings. Based on the correlation analysis results of natural frequency which are stored in the knowledge base, the system searches the most likely error in the model over the knowledge base of possible problems and guides the user to update the model. The performance of the algorithm was verified with two applications: a stick model of a 15 storey residential building and five 3-D finite element models of a 66 storey frame-core wall office tower. The proposed system is verified to be efficient, and the main advantage is the rapid identification of likely problems in the finite element model and the explanation of the physical meaning of the problem.

**Advanced Oxidation Processes Coupled with Membrane Technology for Water Purification**

*Principal Investigator: Chen Dong*

*Report No: CEE/PhD/2002/ 57*

Selecting colloidal humic acid as the target organic contaminants, the feasibility of using photooxidation as the pretreatment process for membrane filtration was investigated. Based on the mechanism study in H2O2/UV system, a kinetic model was developed to optimize the photooxidation process. The increasing level of carbonate and bicarbonate ions declined the photooxidation rate. Through the pretreatment of photo oxidation, the average particle size of humic acid decreased while its zeta potential became more negative at pH 7.0 compared with original humic acid solution. The results of the filtration test revealed that the permeate flux, the rejection rates of TOC and Color400 of oxidized humic acid solutions were better than the original humic acid solutions. More negatively charged membrane was effective in treating the original or oxidized humic acid solutions. The parameters found in this study can be used in a scale-up system for the treatment of natural water or biologically treated effluent.

**Effects of Fractures on Wave Attenuation In Rock Masses**

*Principal Investigator: Cai Jungang*

*Report No: CEE/PhD/2001/ 58*

It is commonly recognized that fractures can result in the attenuation of stress wave amplitude and the slowing of stress wave propagation velocity. The effects of rock fractures on wave amplitude attenuation in fractured rock masses are a fundamental interest in solving the problems of seismic investigation, rock mass dynamics and protective engineering. This study investigated a) the effects of multiple parallel fractures with a linear deformational behaviour on small-amplitude stress wave attenuation, b) the effects of a single fracture with a loading rate-independent nonlinear normal behaviour on large-amplitude stress wave attenuation, and c) the effects of a single fracture with a loading rate-dependent nonlinear normal behaviour on large-amplitude stress wave attenuation. The fractures studied are planar, unsaturated and of a large extent and a small thickness relative to wavelength. The approaches taken in the study include theoretical analyses, laboratory experiments and discrete element modelling.