Two-Day Course on Earthquake Ground Motions and Responses of Reinforced Concrete Buildings

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THE two-day course on "Earthquake Ground Motions and Responses of Reinforced Concrete Buildings" was organised by the Civil and Structural Engineering Technical Division of IEM, in collaboration with the IEM Technical Committee on Earthquake. The event was held on 22-23 June 2010 at Armada Hotel, Petaling Jaya, and was attended by 87 participants.

Professor Dr Nelson Lam from the University of Melbourne, Australia, is an internationally recognised expert in earthquake engineering and structural dynamics, and served as a member of the subcommittee for developing the new standard for Earthquake Actions in Australia. He has done extensive research and is active in consultancy work in this field and has published 200 technical articles in earthquake engineering and structural dynamics in journals worldwide.

Dr Hing-Ho Tsang, currently a lecturer at the University of Hong Kong, is also actively involved in the field of earthquake engineering and has published 60 technical articles. He has given several lectures internationally, notably the keynote speech at the Australian Earthquake Engineering Conference in 2008.

The first speaker, Professor Dr Lam, began by presenting an overview on the occurrence of earthquakes, the source of an earthquake and its relation to ground motion and the path of propagation of seismic waves with reference to attenuation modelling. The fundamentals of seismic activity, the use of tectonic maps and seismic hazard maps and earthquake modelling was explained in detail. This was followed by Dr Tsang's lecture on Seismic Hazard Analysis for regions of low to moderate seismicity. The major topics covered on the first day of the course were:

EARTHQUAKE BASICS, GROUND MOTION PROPERTIES AND RESPONSE SPECTRA

Earthquakes occur mainly due to high stresses in the Earth's crust (caused by tectonic activity) that results in the rupture of the crust at the weakened planes along fault lines. The fault rupture mechanism can be caused by either vertical movement in the form of normal or thrust faulting, and/or horizontal movement in the form of transcurrent or transform faulting. The different earthquake magnitude scales such as the Richter (local) magnitude, surface wave and moment magnitudes and the ground motion characteristics in terms of mass, time, velocity and displacement (fault length) were elaborated.

The damping mechanism and elastic response behaviour of structures were presented using the single degree of freedom systems. The peak ground acceleration (PGA), peak ground velocity (PGV) and peak ground displacement (PGD) together with the pulse wave duration, effects of damping and the acceleration time-history affecting the response of the structure were emphasised. Finally, the use of typical earthquake response spectra diagrams and its co-relation with PGA, PGV and PGD (shown in tri-partite format) and the site soil effects were established.

INTRODUCTION TO ATTENUATION MODELLING

The different types of attenuation models, namely, empirical, semi-theoretical, intensity and stochastic models and the effect of Source (magnitude), Path (distance and attenuation) and Site Conditions (rock, soil, *etc*) on the Structure (hazard and prediction for the intensity of ground shaking) were discussed. The attributes, advantages and disadvantages of these different types of attenuation models proposed by various researchers and the Modified Mercalli Intensity (MMI) scale of seismic intensity were highlighted.

SEISMIC HAZARD ANALYSIS (SHA) FOR REGIONS OF LOW-MODERATE SEISMICITY

Two basic methods (deterministic and probabilistic approaches) for SHA, their procedures of application and the merits of using the different alternative methods for SHA by various researchers were demonstrated with the aid of case studies from different countries. The lessons from low-probability large-consequence earthquakes based on known damage to properties, recorded injuries and number of deaths, worst-case scenarios, great earthquake uncertainties at large magnitude range and the benchmark return period for zoning maps using past records were documented.

COMPONENT ATTENUATION MODEL (LEVEL 1)

The background and basis for the development of the response spectrum for seismic design using the parameters of Acceleration, Velocity and Displacement to formulate the Component Attenuation Model (CAM) was elaborated in detail. The formulae of maximum Velocity and Displacement and its relation to the radius of 30km on hard rock, energy absorption along travel path, geometrical spread of energy, presence of rock crusts and soil sediments was introduced. The results computed using the formulae when compared with actual recorded data showed a good degree of conformity and were on the conservative side. The speaker has used numerous examples for illustrating the CAM formulae, and tables and charts were also developed for ease of reference.

COMPONENT ATTENUATION MODEL (LEVEL 2)

Further demonstration of the CAM stochastic simulations of ground shaking was carried out to incorporate the sum of harmonics of different frequencies and amplitudes and, after the filtering process, the response spectra and ensemble averaging was achieved. Source modelling, path attenuation modelling and upper crustal modelling were introduced to enhance the CAM for real life applications. In addition, further development of the CAM was undertaken at the site and computations were carried out to check and verify the results obtained from differing models at numerous case studies within Australia, Hong Kong, Northern Iran, China, Taiwan and the Sumatran-Malaya regions.

A question and answer session was conducted before the end of the first day of the course. Professor Dr. Lam informed the course participants that 2.5% of gravitational acceleration was stipulated as the lateral seismic force to be catered for in Building Design for some countries. He mentioned that sufficient data needed to be obtained in order to use the probabilistic approach for SHA. Besides replying to questions from the audience, additional explanations were also given for peak ground acceleration.

On the second day of the course, Professor Dr Lam covered the following major topics:

ANALYTICAL STATIC METHOD FOR SEISMIC DESIGN

The concept and procedures for the calculation of the elastic deflection in buildings, the Effective Displacement, the Effective Mass, the Effective Stiffness, the Effective Natural Period and the Performance Point were introduced. The use of approximate hand calculation procedures for building displacement of low-rise buildings and the construction of capacity diagrams for linear elastic systems were emphasised.

He also demonstrated the steps for estimating the response behaviour of reinforced concrete building structures to earthquake ground shaking and the determination of seismic displacement demand using the Acceleration-Displacement Response Spectrum (ADRS) diagram. This was also extended to cater for non-linear systems. All these computations were illustrated with actual examples.

DISPLACEMENT CONTROLLED BEHAVIOUR FOR APPLICATION IN LOW AND MODERATE SEISMICITY REGIONS

The use of Peak Displacement Demand (PDD) for the displacement controlled behaviour of structures and the use of a single pulse were explained. The relationship between the acceleration response spectrum, velocity response spectrum and displacement response spectrum diagrams and the corresponding relationship formulae was explained using actual examples.

The analysis of the overturning stability of freestanding objects of varying heights and widths using the PDD diagram showed a linear relationship. Two case studies for the assessment of a historical structure and a soft-storey building using PDD were illustrated.

DEFORMATION MODELLING OF REINFORCED CONCRETE (RC) SECTIONS

The concept of Effective Stiffness of RC sections was introduced together with the post yield stress-strain relationship between concrete and steel reinforcement. The modelling of RC sections in bending deformation, plastic hinge rotation and shear deformation modelling for uncracked and cracked concrete were explained and illustrated by spreadsheets (using an iterative process) for the different section types and arrangement of rebars. The shear deformation for cracked concrete was modelled using a truss analogy and the shear deformation was shown to be affected by the shortening of the struts, lengthening of stirrups and longitudinal reinforcement.

DISPLACEMENT CAPACITY OF BUILDING STRUCTURES

The deflection of a RC cantilever wall at yield and a coupled shear wall was analysed up to the limit of steel yielding. The ultimate post-yield displacement capacity of the RC cantilever wall (yield and plastic rotation), and the design and analysis of confined concrete was analysed. In addition, general recommendations for the confinement detailing of fully ductile RC elements to avoid the buckling of rebars were explained.

IN CLOSING

Professor Dr Lam also shared his findings on the damage investigation (shown using photographs) caused by the Magnitude 5 earthquake in the Kalgoorlie-Boulder area of Western Australia. He highlighted his findings that small features such as short parapet walls and frames tended to fail and collapse, while large or tall structural features remained standing in that particular earthquake event. This gives credence to the displacement capacity concept in determining actual structural response.

During the question and answer session on the final day of the course, Professor Dr Lam explained his views on vertical acceleration, the use of research models, the use of geomorphology data, the push-pull effect on columns & stability of buildings using shear walls, the importance of ductile detailing for earthquake resisting structures and the effect of piled foundations on seismic design and buried underground water tanks.

Finally before the conclusion of the two-day course, a token of appreciation was presented to each of the speakers by Ir. MC Hee in his capacity as Vice-President of IEM, and also on behalf of the organisers. ■