SCIENCE FOR PEACE
ADVANCED RESEARCH WORKSHOP

SEISMIC ASSESSMENT AND REHABILITATION OF EXISTING STRUCTURES

TUBITAK

ABSTRACTS

1. AKKAR, S. & SUCUOĞLU, H.

PEAK GROUND VELOCITY SENSITIVE DEFORMATION DEMANDS AND A RAPID DAMAGE ASSESSMENT APPROACH

Abstract: The effect of peak ground velocity (*PGV*) on the maximum inelastic deformation demand of simple, non-degrading structural systems is studied. Ground motion data sets are assembled for pre-defined ranges of *PGV* and they are used to conduct nonlinear response history analysis of single-degree-of-freedom (*SDOF*) systems. The non-degrading inelastic behavior of *SDOF* systems is accounted by elastoplastic hysteretic model. The study is focused on short and intermediate periods of vibration (*T*) and strength reduction factor (*R*) is used to define structure's lateral capacity. Statistical results of the study indicate a strong correlation between the mean maximum inelastic deformation demand and *PGV* parameter. These results are compared with various procedures that estimate the maximum inelastic deformation demands of simple structures for seismic performance assessment purposes. A simple tool for rapid damage assessment in pre-earthquake evaluation of existing building systems is proposed that combines the ground motion parameter *PGV* with structural properties *R* and *T*.

Key words: Performance-based seismic engineering; Strength reduction factors; Maximum inelastic deformations; Peak ground velocity; Damage assessment

2. BARAN, M., DUVARCI, M., TANKUT, T., ERSOY, U. & ÖZCEBE, G.

OCCUPANT FRIENDLY SEISMIC RETROFIT (OFR) OF RC FRAMED BUILDINGS

Abstract: An innovative non-evacuation retrofitting technique is being developed for reinforced concrete building structures, which constitute the major portion of the existing building stock in the region. The introduction of cast-in-place reinforced concrete infill walls, connected to the existing frame members, is known to be very effective in improving the overall seismic structural performance. However, this technique is not suitable for strengthening of the existing building stock, since it involves messy construction works and requires evacuation. The idea behind the proposed method is to transform the existing hollow masonry infill walls into strong and rigid infill walls by reinforcing them with relatively high strength precast concrete panels epoxy glued to the wall and epoxy connected to the frame members. The panels to be assembled on the wall should be small enough to be handled by two workers.

Apart from two preliminary tests guiding the improvement of the newly developed test set-up, three tests have so far been performed satisfactorily. The first specimen was designed to represent the present state of an ordinary reinforced concrete frame with hollow brick infill walls plastered on both sides, and meant to serve as reference for the strengthened specimens. The infill walls of the other two specimens were strengthened with epoxy glued precast concrete panels of different geometry. All specimens were tested under reversed cyclic loading. Both of the strengthened specimens exhibited superior behaviour and capacity compared to the reference specimen, indicating practical potential of the proposed retrofitting technique.

Keywords: Seismic retrofit, seismic strengthening, seismic repair, infilled frames, lateral stiffness improvement.

3. ERDEM, İ., AKYÜZ, U., ERSOY, U. & ÖZCEBE, G.

A COMPARATIVE STUDY ON THE STRENGTHENING OF RC FRAMES

Abstract: Due to various deficiencies and inadequate lateral stiffness many reinforced concrete buildings are highly damaged or collapsed in Turkey during the last major earthquakes. In order to improve the behavior of such buildings and in order to prevent total collapse, necessary amount of strengthening must be provided. The frame of the test specimen (1/3 scaled, 2-story, 3-bay) is detailed such that it has the common deficiencies of existing buildings in Turkey. Two types of strengthening techniques, namely introducing an infill RC wall, and CFRP strengthened hollow brick wall, are investigated. The test specimens are subjected to reversed cyclic quasi-static loading. By means of special transducers, axial force, shear force and bending moment at the base of the exterior columns are measured. Strength, stiffness, and story drifts of the test specimen are determined.

Keywords: Earthquake, reinforced concrete (RC), strengthening, earthquake resistance, carbon fiber reinforced polymer (CFRP)

4. ERDURAN EMRAH & YAKUT, A.

PARAMETERS AFFECTING DAMAGEABILITY OF REINFORCED CONCRETE MEMBERS

Abstract: Recent focus on developing procedures for predicting earthquake-imposed damage on buildings has found broad appeal because there has been extensive need for such procedures. These procedures are used for the purpose of evaluating performance of existing buildings as well as assessing building vulnerability. Predicting vulnerability of a whole structure is not an easy task due to lack of proper experimental and observed data. For this reason, the trend has moved towards evaluating the whole structure at the level of its components. In this framework, research has been undertaken to develop damage curves for reinforced concrete members. Columns, beams and shear walls are considered as primary components of reinforced concrete buildings and infill walls as secondary components. Since available experimental studies on this subject are limited, a broad range of parameters that influence the damageability of reinforced concrete members are investigated analytically. Analytical results are calibrated with available experimental data to determine the significant parameters that need to be considered in the damage curves. This paper deals with the first stage of the aimed study, which is the determination of all significant parameters that affect the damageability of RC components. Analytical investigations for columns and beams are presented for a broad range of parameters, emphasizing on their effect on the structural damage. These results will then be used to develop damage curves that are expressed in terms of inter story drift ratio. Once component level investigations are completed, story and then building level damage functions will be developed.

Keywords: Reinforced Concrete, Damage Curves, Deformation, Drift

5. *ERSOY, U., ÖZCEBE, G., TANKUT, T., AKYÜZ, U., ERDURAN, E. & ERDEM, İ.*

STRENGTHENING OF INFILLED WALLS WITH CFRP SHEETS

Abstract: Strengthening of framed structures by introducing reinforced concrete infills to the selected bays in both directions would be an effective and acceptable approach for the existing buildings having various deficiencies. However, once this technique is adopted for the strengthening of building in use, the building needs to be evacuated before starting the construction, which will last for several months. This would impair the practicality of strengthening by reinforced concrete infills. Hence, it can be said that strengthening techniques which could be applied without interrupting the functioning of the building are urgently needed. In this study, it was intended to use the existing partitions and non-load bearing exterior masonry infills as structural walls by strengthening them with CFRP strips. Tests have been carried out at METU to develop an efficient method of strengthening based on this reasoning. This paper reports the test results related to frames having hollow clay tile infills strengthened by using CFRP.

Key words: Seismic strengthening, existing buildings, reinforced concrete frames, brick masonry infill, CFRP, experiment, cyclic loading

6. *FARDIS, M.N. & BOUSIAS, S.N.*

SEISMIC ASSESSMENT AND FRP-RETROFITTING OF EXISTING RC BUILDINGS

Abstract: In the light of our current knowledge and of modern codes, the majority of buildings stock and other types of structures in most of the world are substandard and deficient. This is especially so in earthquake-prone regions, as, even there, seismic design of structures is relatively recent. In those regions the major part of the seismic threat to human life and property comes from old buildings.

Due to the infrastructure's increasing decay, frequently combined with the need for structural upgrading to meet more stringent design requirements (especially against seismic loads), structural retrofitting is becoming more and more important and receives today considerable emphasis throughout the world. More importantly, in recognition of the importance of the seismic threat arising from existing substandard buildings, the first standards for structural upgrading to be promoted by the international engineering community and by regulatory authorities alike are for seismic rehabilitation of buildings.

A detailed seismic assessment (or evaluation) of an individual building, not only determines the potential need for seismic retrofitting, but also identifies the particular weaknesses and deficiencies to be corrected through retrofitting. For this reason recent years have seen a worldwide shift from rapid screening and empirical evaluation methods, to fundamental assessment procedures based on a direct or indirect comparison of the inelastic deformation demands to the corresponding deformation capacities.

This paper consists of two parts. In the first, two procedures of different sophistication and complexity are proposed for the seismic assessment of existing RC buildings, with or without masonry infills. Both are based on seismic displacements and the associated chord rotation demands at member ends. In the simpler procedure, that may be used for preliminary evaluation of buildings, inelastic chord rotation demands may be estimated from linear elastic analysis, while forces for the check of brittle failure modes are computed from in a capacity-design fashion. In the more advanced procedure, that may be used for final or detailed evaluation, inelastic chord rotation demands and member shear forces are determined via nonlinear static (pushover) analysis. Verification criteria at three different performance levels are proposed for each one of the two evaluation procedures. The two procedures differ also in the amount and type of information on material properties and quantity of reinforcement required for their application. In the 2nd part of the paper, an on-going experimental program on retrofitting of RC columns is described. The program focuses on two aspects: a) retrofitting of deficient lap-splicing of ribbed reinforcement through FRP wraps, and b) the effect of the number of CFRP layers on the effectiveness of retrofitting.

Keywords: CFRP, methods of seismic assessment of buildings, retrofit, performance levels.

7. GARCIA, L.E.

EARTHQUAKE ENGINEERING, SEISMIC VULNERABILITY ASSESSMENT AND SEISMIC REHABILITATION IN COLOMBIA

Abstract: The tectonics and seismicity of northwestern South America are presented. The construction types prevalent in Colombia are discussed. A brief description of the Colombian earthquake resistant regulations is given, for both the 1984 Code and the 1998 update. The behavior of buildings during earthquakes previous to the Code enactment is presented. The accelerographic records obtained during the January 25 1999 earthquake are described and the building damage caused by the earthquake is discussed, along with the statistics of building type, height, and usage. The Code compliance and enforcement is discussed. Issues associated with seismic vulnerability assessment and building retrofit in Colombia are presented. It describes issues related to the Colombian experience in seismic vulnerability assessment of school buildings and bridges and their rehabilitation.

Keywords: Colombia 1999 Earthquake; Colombian Seismic Code; Earthquake Engineering in Colombia, Field observations, Accelerographic Records, Building Damage, Construction Types, Response Spectra, Structural Behavior, Seismic Rehabilitation, Seismic Vulnerability Assessment

8. GAREVSKI, M., PASKALOV, A. & TALAGANOV, K.

EXPERIMENTAL AND ANALYTICAL INVESTIGATIONS OF A 1/3 SCALEMODEL OF A 4 STORY R/C FRAME-WALL BUILDING STRUCTURE

Abstract

This paper presents a preliminary experimental dynamic test and associated analytical work on a 1/3-scale model of a 4-story full-scale frame structure with infill walls tested at IZIIS as part of the NATO-Science for Peace project SfP 977231 “Seismic Assessment and Rehabilitation of Existing Buildings”.

Keywords: shaking table modeling, experimental tests, seismic analysis

9. GÜLKAN, P., BAKIR, B.S., YAKUT, A. & YILMAZ, M.T.

JUST HOW PRESCIENT ARE OUR BUILDING DAMAGE PREDICTIONS?

Abstract

Adapazarı was the scene of spectacular structural damage as well as widespread liquefaction that occurred in the city after the devastating earthquake of August 17, 1999. The damage patterns observed in Adapazarı are re-examined in an effort to answer the question of whether they are indicative of a consistent trend explicable in terms of the building attributes and/or site conditions. For this purpose a total of 301 buildings that had collapsed fully have been re-evaluated. This exercise was necessarily a desk study conducted from the design blueprints of the individual buildings that no longer existed. All buildings were rated from the view of conventional seismic performance using accepted parameters to confirm the observed damage. An examination based solely on structural attributes, including also data from other sets of building assessment projects, leads us to believe that building collapse is perhaps just too involved to reduce to a few simple guilt pointers. Site effects might have played a major role in the observed damage, because only a conflicting trend between structural attributes and the actual damage can be established.

Keywords: Damage assessment, Site effects, Seismic evaluation

10. KARADOĞAN, F., YÜKSEL, E. & İLKİ, A.

EXTERIOR CARBON OR GLASS FIBERS USED TO STRENGTHEN ORDINARY RC FRAMES WITH BRITTLE PARTITIONING

Abstract: Brittle partitioning walls have been widely used almost in all weakly reinforced and poorly constructed reinforced concrete low cost, low rise buildings of big cities located in the earthquake prone areas of this Country. One of the strengthening alternatives of these vulnerable buildings has been realistically examined by ½ scale tests in Istanbul Technical University (ITU) within a broader framework of an experimental program launched by NATO. The early results of these tests, which are going on, have been put together and been presented in this paper. Since lap splicing deficiency in columns has been selected as one of the major factors for early collapse of buildings, two similar sets of one bay-two story pair specimens have been fabricated with and without lap splicing deficiency. From each set, one specimen is tested as bare frame and the other specimen is tested as infilled frame. Local engineering practice and local materials have been utilized during the manufacturing process of the specimens. All specimens have been tested controlling the lateral load first up to 60% of the predicted ultimate load and displacement control has been employed later on, till approximately 4 displacement ductility is reached. Only one reverse cycle has been applied to the specimens at each level of target displacement. The progress of the damage during the test steps has been documented carefully. As well as the details of this work and the early results achieved at the end of these tests, the theoretical predictions are also presented herein.

Key words: brittle partitioning, infill wall, reinforced concrete frames, strengthening

11. ÖZCEBE, G., YÜCEMEN, M.S., AYDOĞAN, V. & YAKUT, A.

PRELIMINARY SEISMIC VULNERABILITY ASSESSMENT OF EXISTING REINFORCED CONCRETE BUILDINGS IN TURKEY

Abstract: This study focuses on modifying the vulnerability assessment procedure developed based on the structural characteristics of buildings located in the city of Düzce. The procedure, which is described in detail in the companion paper [1], relies on the damage cutoff values developed using a statistical analysis approach based on the damage data compiled from Düzce in the wake off 1999 eartquakes. Some selected building attributes are entered into a relation obtained from discriminant anaysis to compute a damage score. This damage score is then compared with a cutoff value, which identifies the building as “safe”, “unsafe” or “intermediate”. The cutoff values recommended are considered to be valid for damaging earthquakes and the regions that have similar distance to source and site conditions to that of the studied area in Düzce. To apply this procedure to the sites, which have different distance to source and soil properties than Düzce, modifications to the cutoff values have been computed. The effects of the distance to source and soil type are the two main parameters considered, since the size of the earthquake considered is assumed to be similar to that of Düzce. Ths sites are classified according to Turkish Seismic Code’s [2] definitions based on the shear wave velocity. Various attenuation relations are used to account for the variation of ground motion with distance and soil type. The modified cutoff values have been applied to Istanbul to get an estimate of what percentage of the buildings would perform unsatisfactorily if an expected earthquake of the same magnitude as Düzce takes place in the vicinity of Istanbul.

Keywords: Attenuation Model, Building Damage, Site Effect, Vulnerability Assessment

12. ÖZDEN, Ş., AKGÜZEL, U. & ÖZTURAN, T.

SEISMIC RETROFIT OF R/C FRAMES WITH LAP SPLICE PROBLEM IN COLUMNS

Abstract: This study is a part of the research program that is carried out within NATO Project 977231 "Seismic Assessment and Rehabilitation of Existing Buildings". Within the framework of the research program a new seismic retrofitting method is experimentally investigated. The behavior of hollow brick infilled reinforced concrete frames strengthened by Carbon Fiber Reinforced Polymers (CFRP) is studied. The main deficiencies of the one-third scale one-bay, two-story frames tested were insufficient column lap splice length, poor confinement, and inadequate anchorage length of beam bottom reinforcement. In all specimens beams were stronger than columns and no joint shear reinforcement was used.

Key words: Seismic Retrofit, CFRP, R/C Frame, Lap Splice, Anchorage Length, Brick Infill

13. PITILAKIS, K.

THE USE OF MICROTREMORS FOR SOIL AND SITE CHARACTERISATION AND MCROZONATION APPLICATIONS

Abstract: Array measurements of microtremors is an interesting and low cost technique for soil and site characterization in the framework of microzoning studies .Using the Spatial Autocorrelation Method (SPAC) a circular array of few broad-band instruments allows the determination of accurate and detailed Vs profiles. A Rayleigh wave inversion scheme (stochastic method), was applied following the determination of phase velocity dispersion curves, for different frequency range windows (<7Hz). The developed methodology is capable to reach a depth of 300m with small array apertures (approx. 50m). The method has been validated at the EUROSEISTEST experimental site (http://euroseis.civil.auth.gr) and then it has been applied in the city of Thessaloniki. Comparisons with Vs measurements from cross-hole and other geophysical techniques (SWI/SASW) proved the accuracy and the reliability of the method. The estimated Vs profiles combined with other existing geothechnical and geological data allowed the construction of 3D geotechnical maps in GIS, describing the Vs velocities of soil formations and their stratification from the surface to the seismic bedrock. The stratigraphy is validated with simultaneous HVSR measurements, giving the amplification ratio and the predominent frequencies at different sites. The accuracy of the Vs profiles, the capacity to reach large penetration depths in densely populated urban areas and its low cost compared to conventional geophysical prospecting, make Mictrotremor Exploration Method (MEM) very attractive and useful for microzonation and site effects studies.

Keywords: microtremors, soil and site characterization, shear wave velocity, stationary random functions, spatial autocorrelation method, site effects, microzonation.

14. SAATCİOĞLU, M.

SEISMIC RETROFIT OF REINFORCED CONCRETE STRUCTURES

Abstract: A comprehensive research program is underway at the Structures Laboratory of the University of Ottawa to develop seismic retrofit methodologies for reinforced concrete structures. The research program consists of different tasks addressing different retrofit techniques. The scope includes external transverse prestressing and fiber reinforced polymer (FRP) jacketing of concrete columns; lateral bracing of masonry infill walls by FRP sheets; lateral bracing of concrete, unreinforced masonry and reinforced masonry walls by steel strips; and the use of smart structure technology. The project involves both experimental and analytical research. The results indicate that the transverse prestressing of columns improve shear capacity, promoting flexural behavior. It also enhances bond stresses between spliced reinforcement and surrounding concrete while confining the compression concrete. FRP jacketing of circular columns results in significant improvements in lateral deformability of columns, while exhibiting limited success in square columns. FRP sheets applied diagonally on masonry infill walls control damage to masonry, improving the elastic capacity of overall framing system significantly without any beneficial effects on ductility. Steel strips placed vertically and diagonally improve strength and deformability of poorly designed reinforced concrete and masonry walls. Active control of seismic deformations, leading to smart structure technology, can reduce inelastic deformations and seismic forces in concrete frame structures.

Key words: concrete; earthquake resistant design; FRP, fibre-reinforced-polymers, masonry walls; reinforced concrete; seismic design; seismic retrofit; shear walls; structural design.

15. SÖZEN, M. A.

THE VELOCITY OF DISPLACEMENT

Abstract: Both the perceived impact and the anticipated magnitude of lateral displacement of buildings in earthquakes (drift) have changed with time since the 1930's when the first movements occurred toward the assembly of detailed professional canons for earthquake-resistant design. This note summarizes some of the highlights that pertain to drift in the development of model codes for earthquake-resistant design in North America to trace the velocity of its travel from an optional check to a central design issue.

Keywords: Rationale of earthquake code, drift, design criteria

16. SUCUOĞLU, H. & YAZGAN, U.

SIMPLE SURVEY PROCEDURES FOR SEISMIC RISK ASSESSMENT IN URBAN BUILDING STOCKS

Abstract: Big cities under significant seismic risk contain a large number of vulnerable buildings. These buildings are the potential sources of life and property losses under an expected damageable earthquake. An effective risk assessment measure in urban areas under seismic risk is to identify the most vulnerable buildings, which may collapse, or damage severely during a future earthquake. Once they are identified properly, urban seismic risk may be reduced either by retrofitting such buildings individually, or by applying urban renewal procedures in areas where their density is high. A two-level seismic risk assessment procedure is proposed in this study. The first level is a street survey, based on recording those building parameters observable from the street side. In the second level, building parameters are extended by structural parameters that can be measured by entering the ground story. Statistical correlations have been obtained for measuring the sensitivity of damage to the selected parameters by employing a database consisting of 477 damaged buildings surveyed after the 1999 Düzce earthquake in Turkey. The results revealed that the parameters observed from the street and measured at the ground story provide strong guidance for identifying those buildings that jeopardize the life safety of their occupants.

Key words: Seismic risk, assessment, buildings, street survey, damage, checklist, score.

17. TÜRER, A.

CONDITION ASSESSMENT TECHNIQUES FOR NON-BUILDING STRUCTURES

Abstract: This paper focuses on 'bridges' and 'historic monuments' for the illustration of condition assessment and measurement techniques. Bridges have special importance among other civil engineering structures not only because they are the weakest chain links of an operational transportation system, but also they have demanding loading conditions of truck traffic, cyclic temperature and dynamic loading, seismic events, and harsh environmental conditions such as freezing and thawing, salting etc. Condition assessment techniques are spread over a wide range from visual inspection to changing the bridge to an on-site laboratory.

Condition assessment techniques may also be applied to other 'non-building' structures such as historical monuments. The condition assessment studies at the Nemrut historical site conducted in the summer of 2002 are selected as an example. This document attempts to summarize the techniques giving brief examples from previous projects.

Key words: condition assessment, measurement, historic, bridge, evaluation

18. ÜZÜMERİ, Ş.M. & ÜZÜMERİ, Y.

A BUILDING CODE IS OF VALUE ONLY IF IT IS ENFORCED

Abstract: Recent Earthquakes have shown that, to reduce the life and property loss, it is necessary to have good building codes and to have the provisions of these codes enforced. This paper discusses the issues related to enforcement of Building Codes and, using Canadian experience, provides a road map for an effective system to enforce the provisions of the Building Codes.

Keywords: Building Code Enforcement, Inspection, Supervision of Construction, Earthquake Damage Reduction, Regulatory Agencies

19. WASTI, S.T. & ERSOY, U.

BRINGING TO BUILDINGS THE HEALING TOUCH

Abstract: Civilization and civil engineering are intimately connected, and few animate – inanimate relationships are deeper or more enduring than those between human beings and their built environment. This interactive relationship goes back thousands of years, and incorporates not only the construction of buildings but also their repair and strengthening. The assessment of how a given building will react to a natural disaster such as an earthquake requires a detailed technical examination of the architectural features and engineering design. Structural damage can always be investigated after it has occurred, but the greater responsibility is to pre-empt such damage by understanding and suitably equipping a building in advance to resist the onslaught of disaster.

Keywords: Structural rehabilitation, seismic behaviour, technical insight, assessment, appraisal, system amelioration.

20. WASTI, S.T.

EDUCATIONAL ASPECTS OF SfP 977231 – SPREADING THE INSIGHT

Abstract: Training to become an engineer is a demanding process and, at the end of their formal period of study, most engineers are content to graduate and rush out to join the professional world of analysis and design. As time passes and responsibilities increase, however, engineering graduates usually feel the need to update and upgrade their knowledge but find it difficult to retrace their steps and pursue a formal course of study. Continuing education is an attempt to update knowledge acquired at the university so that the engineer can successfully face the challenge of technical change. In addition to their basic duties of teaching and research, universities should provide special courses for practising engineers and thus maintain an organic link with their former graduates. All research projects possess, produce or provide an educational content. The upward distillation of knowledge leads to wisdom; the filtering down of knowledge leads to know-how. Engineering research always incorporates practical implications and most research projects provide sufficient educational spin-off for immediate application in teaching, training, distance learning as well as routine professional life. However, the absence of a suitable nexus between the producers and the consumers of know-how results in vast areas of expertise remaining untapped and unexploited. Attempts should therefore be made to ensure smooth, timely and proper transmission and dissemination of research results in digestible form to practising engineers. This is easier said than done; the difficulty lies in the attractive packaging and comprehensible presentation of technical material and in ensuring that such transfer be effected both efficiently and swiftly. For large – scale applications, management techniques would need to be implemented.

NATO SfP Project No. 977231 in the area of Seismic Assessment and Rehabilitation of Existing Buildings possesses, as one of its most important parts, an educational component. Direct and indirect information from the project is being and will be processed and disseminated to the technical community in user – friendly and accessible forms and formats to increase preparedness in the event of future disasters. It is a description, dissection and discussion of these aspects of the project that comprises the material for the present report.

Keywords: Dissemination of technical information, continuing education, seismic technology transfer, specialized distance learning.

21. YÜCEMEN, M.S. & ASKAN, A.

ESTIMATION OF EARTHQUAKE DAMAGE PROBABILITIES FOR REINFORCED CONCRETE BUILDINGS

Abstract: Due to uncertainties involved both in the occurrence of earthquakes and in structural response, earthquake damage prediction has to be treated in a probabilistic manner. In this study two statistical methods are presented for the prediction of potential seismic damage to low and mid-rise reinforced concrete buildings in Turkey. These methods are based on the utilization of damage probability matrices and reliability theory. The damage data compiled during recent earthquakes that occurred in Turkey are used to compare the predictions of these two methods.

Keywords: earthquake damage estimation, damage probability matrix, fragility curves, seismic resistance index, reliability theory, Düzce earthquake