Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Method for evaluation of the seismic resistance of existing reinforced concrete buildings

G.S. Necevska-Cvetanovska & B.S. Simeonov
Institute of Earthquake Engineering and Engineering Seismology, University 'Kiril and Metodij', Skopje, Republic of Macedonia

ABSTRACT: The experience from occurred strong earthquakes during the past 20 to 25 year period has shown that reinforced concrete buildings suffered damage and even failure, although constructed in compliance with existing national Code for design and construction in seismic regions for the given countries. It shows that in any urban area, basides many old buildings, there is a large number of modern reinforced concrete buildings which do not meet the requirements of additionally adopted Codes for design and construction of buildings in seismic areas. The objective of these investigations is to define a method which will make possible evaluation of the seismic resistance of a large number of existing reinforced concrete buildings, i.e., predicting of their behaviour under future earthquake effect.

1. INTRODUCTION

There is a number of methods for evaluation of the seismic resistance of existing reinforced concrete buildings, applied currently in the world, however they have been elaborated to be applied to typical reinforced concrete buildings constructed in a considered country, so that their direct application into another country is not possible.

The definition of such a method is a wide and complex problem. One one hand, it is necessary to carry out the most possible realistic definition of the structural system capacity, in terms of strength and deformability capacity of the system,, and on the other hand, after having selected the expected earthquake effect on a given site, in terms of intensity, frequency content and time duration, to predict as realistically as possible the nonlinear behaviour of the structure, and on the basis of these results to define the earthquake, i.e., the seismic force or the acceleration that would cause damage to structural elements and the integralgral structural system. For this purpose, it is necessary to develop a computer programme that will enable a fast and simple way for coming to the desired results. As a result of the analytical studies, carried out at the Institute of Earthquake Engineering and Engineering Seismology in Skopje, a method has been developed for a fast and simple evaluation of the seismic resistance of the existing reinforced concrete buildings of small and moderate numbe of stories. In fact, the developed method incorporates the latest knowledge gathered in our country and the worldwide experience from the broad fields of the earthquake engineering: determination of strength and deformability characteristics of the building, on one hand, and definition of the nonlinear behaviour of the structure for a given earthquake effect, on the other hand.

2. METHOD FOR EVALUATION OF THE SEISMIC RESITANCE OF REINFORCED CONCRETE BUILDINGS, DEVELOPED AT IZIIS - SKOPJE

The method for evaluation of the seismic resistance of reinforced concrete buildings, accepted at IZIIS, consists in the following five steps:

1. Definition of the structural system of the building and determination of the quantity and quality of the built-in material.
2. Determination of the Q-Δ diagram for each element, separately, and the storey Q-Δ diagrams.
3. Definition of the seismic parameters and the design criterria.
4. Nonlinear dynamic analysis of the structural system for a given earthquake effect.
5. Evaluation of the seismic resistance for the given structure.

Graphic presentation of the method is given in Fig. 1.

Described futher on, is the method and the steps required for evaluation of the seismic resistance of the considered building, while the practical application will be presented on an actual example.

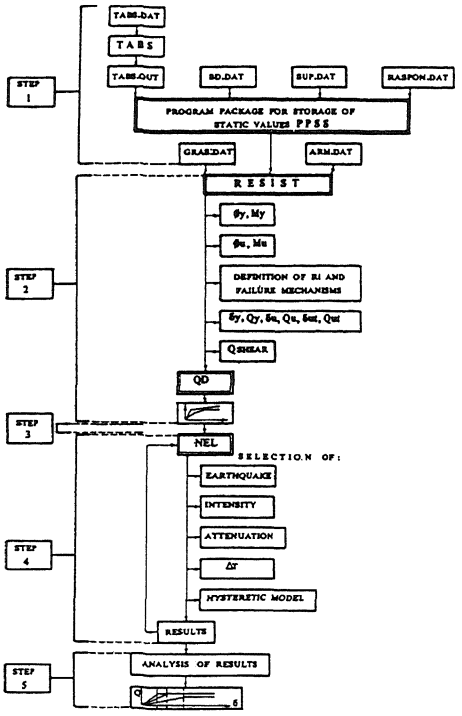


Figure 1. Graphic presentation of the method.

2.1. Definition of the structural system of a building and the quantity and quality of built-in material

The initial step for evaluation of the seismic resistance of a building is the definition of the structural system of the building as well as the quantity and the quality of the built-in material. The main information on the building, such as the structural type, number of stories, kind, quantity and quality of built-in material can be obtained from the design documentation for the considered building. For older buildings, it is possible that no design documentation is available. In such a case, the building is inspected for an in situ determination of the quantity and the quality of the built-in material.

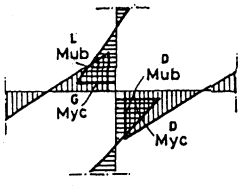
On the basis of the defined schemes of frames and walls distribution with the proportions of the elements and the defined vertical loads and seismic forces, elastic analysis of the structure is carried out applying TABS computer program.

Using a special ARMA,DAT database, the *quantity and the quality of the used steel* reinforcement for each structural element cross sections (columns, walls and beams) are entered. By the related computer programs, developed by the author for each cross section for the whole building, the internal forces M, Q and N are arranged for each structural element, i.e., frame-wall, in the columns and beams and for each loading pattern. The databases, prepared in this way, are ready to be used with the RESIST computer program for step 2.

2.2. Determination of Q-Δ diagram for each element and the storey Q-Δ diagrams

The strength and deformability characteristics of each element of the building can be determined applying the RESIST computer program, by which, starting with the elastic analysis of the structure performed applying the TABS program and the known quantity and quality of the built-in steel reinforcement and the attained compressive strength of the concrrete in all the cross sections of the elements (columns, beams and walls), for each storey element, separately, it is possible to obtain the yield displacement δ_y, the shear force at yielding Q_y, the maximum displacement δ_u, the shear force at maximum displacement Q_u. At the same time, the shear strength of each element of the building is determined, according to the Arakawa and Ohno method taking into consideration that no shear failure of the element occurs. Having the Q-Δ diagrams for each element and storey, applying the QD.FOR computer program summarizing of the Q-Δ diagrams is carried out and the storrey Q-Δ diagrams are obtained.

It should be mentioned that the method for determination of the displacement at yield point is based on the known fact that the curvature diagram of the column corresponds to the shape of the bending moment diagam, since the moments are still in the initial linear range of the moment-curvature relationship. The curvature of the column differs for different stories due to the different properties of the cross sections and the level of the axial load. The horizontal displacement of any storey can be determined as a sum of the moments of the areas of the curvature diagrams in respect to that level. Using the RESIST computer program it is possible to follow the moment diagam obtained by the TABS computer program for each storey and it is possible to determine the correct inflexion points at each column line, thus defining the failure mechanism at each joint, separately. Thus, the correction factor Ri can be determined in the following way (Fig. 2):



$$R_i = \frac{M^L_{ub} + M^D_{ub}}{M^D_{yc} + M^G_{yc}}$$

Figure 2. Moment diagram of a joint

R_i - correction factor for i-th storey
M^{ub} - ultimate moment of beam left and right
M_{uc} - yield moment of column up and down.

In the case of development of a plastic hinge in the beams (R_i<1), it is necessary that ϕ_y and M_y of the columns experience adequate corrections (i.e., be decreased since after the development of plastic hinges in these cross-sections, full moment and yielding rotation are not possible to develop in the column.

By correct definition of the inflexion points and the corrected Φ-values (where necessary) the known procedure for determination of ϕ_y and Q_y in the elements should be continued.

During the determination of the horizontal displacements of reinforced concrete walls bending and shear deformations are taken into consideration. For this purpose, the results obtained fom experimental and analytical studies performed at IZIIS in Skopje by Simeonov (1984) are used.

The storey Q-Δ diagrams represent the basis for further nonlinear dynamic analysis of the building.

2.3. Definition of seismic parameters and design criteria

The seismic parameters and design criteria can be determined on the basis of the seismic parameters of the earthquake effect, which in turns can be determined by complex analyses of the regional and local seismological properties of the building site. On the basis of the actual and the local site properties, applying probability methods, evaluation of the seismic hazard parameters is carried out according to which expected maximum ground accelerations for 50, 100, 200 and 500 year return periods are possible to be defined.

For this purpose, several time histories with corrresponding frequency content are suggested to be used for further dynamic anallysis.

After having defined the Q-Δ diagrams for each storey of the building and the seismic parameters of the site of the building, dynamic analysis of the structural system of the building can be carried out.

2.4. Nonlinear response of the building to given earthquake effect

In addition to have studied a large number of experimental and analytical investigations aimed at more realistic definition of the capacity of the structural system of the building, and more realistic selection of corresponding seismic parameters for the given site, intensive investigations have been performed aimed at defining different hysteretic models through which it is possible to carry out the most realistic presentation of the behaviour of the structural system under a given earthquake effect. This problem has been a very interesting and challenging subject for many investigations in the world, therefore a large number of hysteretic models have been proposed to be used for prediction of the response of the reinforced concrete elements and the structure to cyclic loads. These models can be very simple, such as the bilinear, Clough's as well as very complex, such as those suggested by Takeda and his collaborators. The author of this paper developed a computer subroutines for the three-linear Takeda's model (Fig. 3) and the simplified Takeda's model (Fig. 4). These computer subroutines are incorporated by the author in the already existing computer programs for determination of the response for multistorey buildings for a bilinear model which has been developed at IZIIS as DRK (Dynamic Response of Structures). The mathematical model of the structure is represented by lumped masses at the floor structure levels, connected with springs, expressing the storey rigidity of the structure. The response analysis of such an idealized structural system, for an arbitrary ground motion is brought to a solution of a second order differential equations, with time variable coefficients. The input data of the mathematical model are: the masses, storey rigidity, yielding point and plasticity line (obtained by step 2), then the damping and record, in terms of ground acceleration time histoy. As a result of the storey displacements, the velocities and the accelerations for the required portion of a second during the earthquake effect are obtained.

The application of these computer programs makes possible selection of different hysteretic models depending on the structural type and obtaining responses for a large number of ground acceleration time histoies, due to the relatively short computer time requirements and the satisfactory accuracy of the analysis for practical purposes.

The storey drifts, the storey shear forces, the relative velocities and the absolute accelerations, obtained as a result of the analyses, represent the basis for step 5 for evaluation of the seismic resistance of the considered structure.

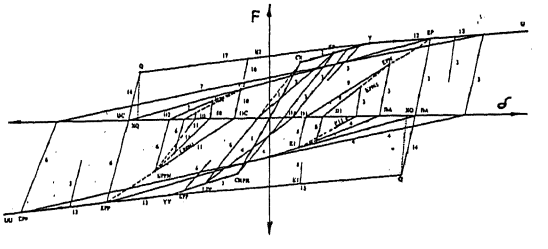


Figure 3. Takeda model.

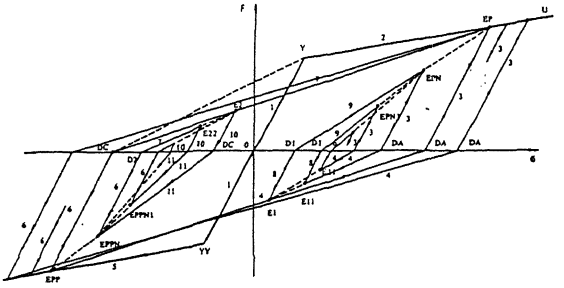


Figure 4. Simplified Takeda model.

2.5. Evaluation of the seismic resistance of the considered building

The results obtained by step 4 (relative storey drifts) are entered in the storey Q-Δ diagrams, i.e., in the Q-Δ diagrams for each structural element, and then it is obvious which earthquake record and which intensity can cause the occurrence of initial cracks, yielding and even failure of the stuctural elements of the building. The evaluation of the seismic resistance of the considered building can be defined by comparison of the nonlinear response "requirements" of the building to the earthquake effect with the ultimate "capacity" of the building.

3. APPLICATION OF THE ACCEPTED METHOD FOR EVALUATION OF THE SEISMIC RESISTANCE TO AN ACTUAL BUILDING

The method for evaluation of the seismic resistance is illustrated on an example of a reinforced concrete building.

3.1. Definition of the structural system of the building and the quantity and quality of the built-in material

The structural system of the building consists of reinforced concrete frames and walls in both orthogonal directions. The plan of the building is 38.4 m, in X, by 12.6 m, in Y direction. Four frames (two and two equal) are formed in longitudinal direction, while in transversal direction totally nine frames are placed at a distance of 4.8 m, out of which six are of R1 and three of R2 type (Fig. 5). The building has five storey

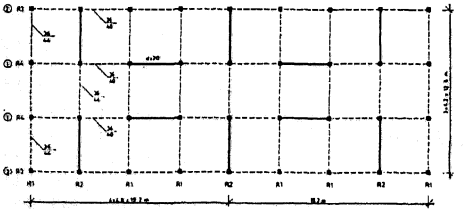


Figure 5. Plan of the building.

levels, each one 3.0 m high. All the columns are of cross-section 40/40 cm, while the beams are 36/40 cm, in longitudinal, and 36/44 cm, in transversal direction. The reinforced concrete walls, 0.20 m in thickness, are totally 5.2 m long, in longitudinal, and 4.6 m long in transversal direction. The floor structure is a flat, reinforced concrete slab.

3.2. Definition of quantity and quality of built-in material

The quantity and quality of the built-in material are obtained from the available design documentation on the considered building. The following are the properties of the built-in material:
- compressive srength of concrete MB 30
- beams, columns, structural walls (longitudinal reinforcement) RA 400/500 with yield stress of 400 MPa.
- beams and columns (shear reinforcement) GA 240/360 with yield stress of 240 MPa
- structural walls (web reinforcement and shear reinforcement) MA 500/560 (Fig. 6).

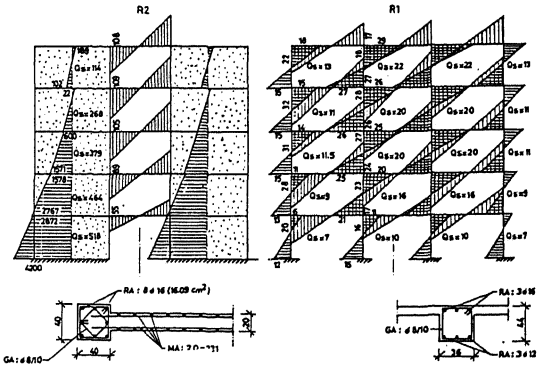


Figure 6. Diagram of moments for frames R1 and R2 and reinforcement details for beams, columns and walls.

3.3. Determination of Q-Δ diagrams for each element, separately, and the storey Q-Δ diagrams

The determination of the strength and deformability characteristics of each element of the building for the corresponding quality and quantity of the built-in material is carried out applying RESIST computer program.

It should be noted that during the determination of the M - ϕ diagrams, in the RESIST computer program, the axial forrce of the structural elements is taken as a sum of the dead, life effect from the horizontal load on the elements. The total axial force is different in all the structural elements, therefore the Q-Δ diagrams are different for all the elements, although their cross sections have the same geometrical characteristics.

Presented in Fig. 7 are the Q-Δ diagrams for the considered building in Y-Y direction, but only for one fragment, consisting of two R1 and one R2 frames. The same figure shows the force-displacement diagrams for the first, third and fifth floor of the building.

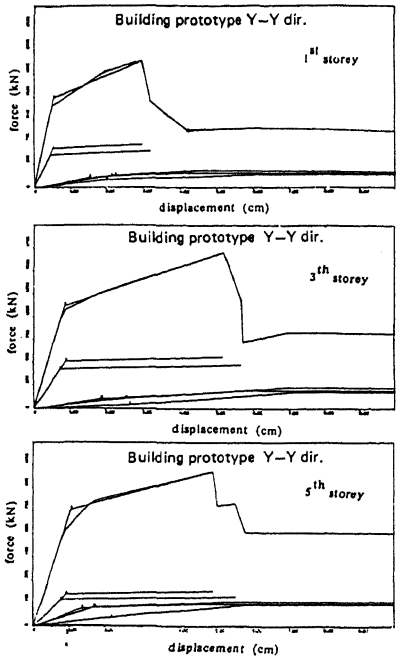


Figure 7. Q-Δ diagrams for the first, third and fifth storey.

3.4. Nonlinear response of the building to given eathquake effect

For the fragment of the existing building, consisting of two R1 frames and one R2 frame, nonlinear response analysis has been carried out for a given earthquake effect. For this purpose, some of the hysteretic models, developed and activated by the author, have been used (Fig. 8).

It is obvious from all the results that the used pattern of the hysteretic models gives different picture of the structural system response to a given earthquake effect, and consequently, different results (relative displacements, total displacements, storey shear force, relative velocity and absolute acceleration), which may result in different evaluations of the seismic resistance of the considered structural system. The earthquake type and intensity have, also, consideable influence on the results. Presented in Fig. 9 are the results of the time histories obtained for the nonlinear dynamic response to the Parkfield earthquake, intensity 0.3 g, Montenegro earthquake (Petrovac - Oliva Hotel) N-S, 0.3 g, Ulcinj (Albatros Hotel) N-S, 0.3 g, and El Centro earthquake 1940, 0.3 g. For each earthquake record a response

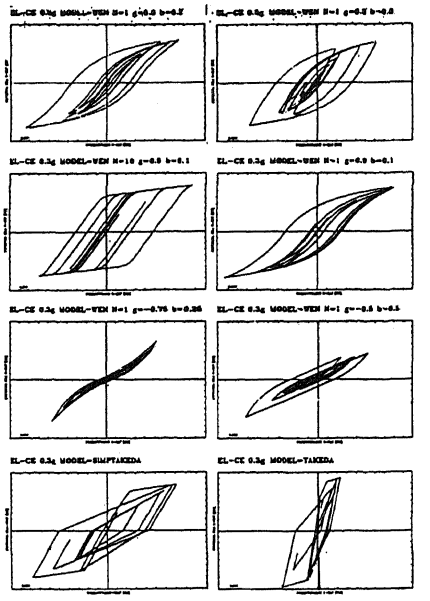


Figure 8. Some of the hysteretical models that can be used in IZIIS.

for three hysteretic models (bilinear, TAKEDA, SIMP-TAKEDA) has been performed. The dotted line in Fig. 10 applies to TAKEDA model. The full line, having the largest value, applies to the SIMP-TAKEDA model. The displacement time history for all the three earthquakes is quite different.

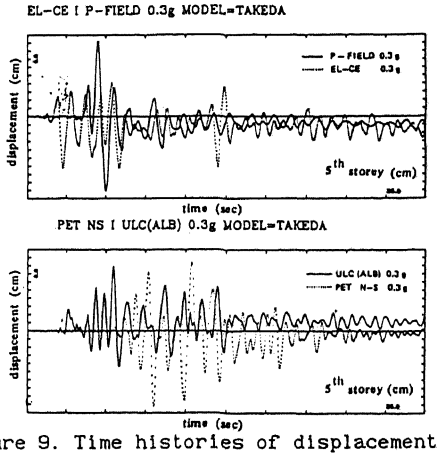


Figure 9. Time histories of displacement at the fifth storey for different earthquakes.

Presented in Fig.10 is the effect of the different intensities of the Montenegro earthquake (Ulcinj - Albatros - N-S) for 0.15 g, 0.3 g and 0.45 g upon the nonlinear response of the structural system. For lower intensities, the smallest displacements are obtained with the TAKEDA model, while in the case of higher intensities, TAKEDA model gives, also, larger displacements, compared to the bilinear model.

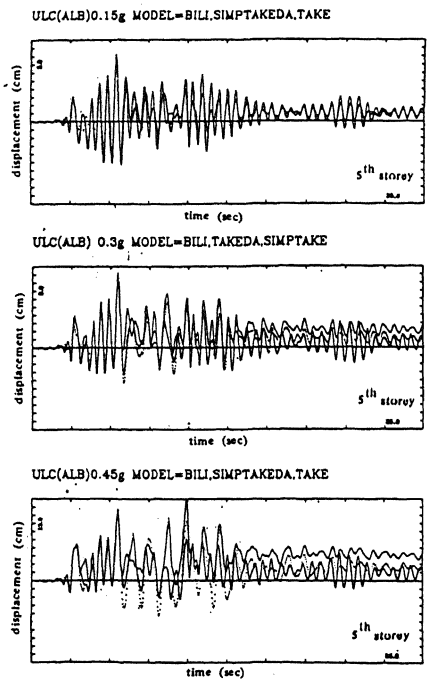


Figure 10. Displacement time histories for different intensities of a single earthquake.

3.5. Evaluation of the seismic resistance of a building

In Fig. 11, the obtained results from step 4 are entered in the Q-Δ storey diagrams.

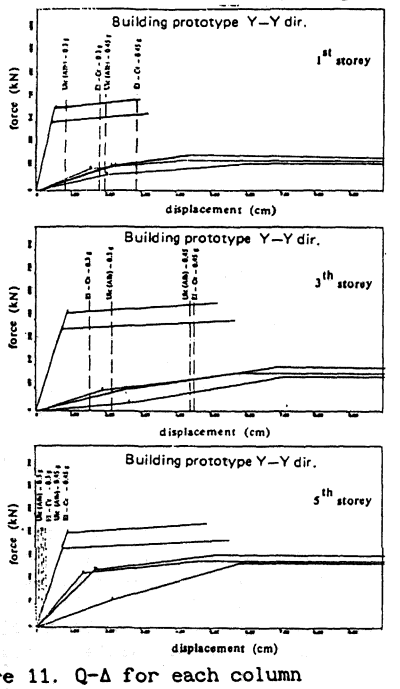


Figure 11. Q-Δ for each column

The maximum relative displacements for the design earthquake level are within the range of 0.8 cm, 2.19 cm and 0.2 cm for the first, third and fifth storey for the El Centro earthquake with 0.3 g. For the maximum earthquake level, the maximum relative displacements are in the range of 2.03 cm, 4.28 cm and 0.16 cm for the first, third and fifth storey, for the Ulcinj (Albatros Hotel) earthquake with 0.45 g up to 2.89 cm, 4.38 cm and 0.25 cm for the first, third and fifth storey, for the El Centro earthquake with 0.45 g. The ductilities are within the range of .5 to 2.59, for the design earthquake level, and from 3.8 to 5.17 for the maximum earthquake level.

On the basis of these results, it can be concluded that the considered building has sufficient seismic resistance for the accepted design level of ground acceleration, while for the maximum expected accelerations it would come closer to this ultimate bearing capacity, however it does not mean failure of the individual structural elements.

4. CONCLUSIONS

The adopted method can be applied for evaluation of the seismic resistance of individual buildings, aimed at their protecting against future earthquakes by strengthening their structures, in case they are determined to be of insufficient seismic resistance. The method can be applied to a larger number of buildings constructed within a urban unit in order to determine the vulnerability level of the area in case of future earthquakes. This method can also be used for testing newly designed buildings aiming at carrying out eventual necessary modifications and improvement of the structures during the phase of final design.

REFERENCES

Nečevska-Cvetanovska, G. 1991. Evaluation of seismic resistance of existing reinforced concrete low and medium-rise buildings. (in Macedonian)Ph.D dissertation, IZIIS.

Simeonov, B.S. 1984. Experimental investigation of the strength, stiffness and ductility of RC structural walls. Proc. Eight World Conference on Earthquake Engineering, San Francisco, Vol. VI: 387-394.

Ohno, K. & T. Arakawa 1966. Experimental studies on shear strength of reinforced concrete beams. Architectural Institute of Japan, No. 66, Tokyo.

Takeda, T., M.A., Sozen & N.N. Nielson 1970. Reinforced concrete response to simulated earthquakes. 1970 Journal of the Structural Division, Proceedings of the American Society of Civil Engineers, Vol. 96, No. ST12