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Earthquake Damage Evaluation for Reinforced Concrete Frames with Infilled Brick Walls

Dégradation de cadres en béton armé remplis de briques sous l'effet de tremblements de terre

Erdbebenschadenschätzung von Stahlbetonrahmen mit Mauerwerksausfachungen

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SUMMARY

An efficient procedure for earthquake damage evaluation of reinforced concrete frames with infilled brick walls is presented. In analysis, the infilled brick walls can be simplified as the equivalent bracing element. The restoring force models with consideration of descending branch for reinforced concrete and infilled brick members are suggested. Pseudo-dynamic tests of two models with two stories and two spans were carried out by a computer-actuated on-line system. The analytical results obtained from elastic, inelastic and collapse response are close to those obtained from corresponding earthquake simulation.

RÉSUMÉ

L'article présente une méthode d'évaluation de la dégradation provoquée par les séismes dans les cadres en béton armé, remplis de briques. L'auteur simplifie son analyse en admettant que les bardages en briques sont équivalents à des poutres en treillis. Il propose des modèles de forces de rappel ayant une forme de branche descendante, aussi bien pour les éléments en béton armé que pour ceux en briques. Les essais pseudodynamiques réalisés ont porté sur deux modèles comportant deux étages et deux travées, soumis à l'action de vérins à commande directe par ordinateur. Les résultats analytiques découlant des comportements élastique, non élastique et à l'état ultime sont sensiblement similaires à ceux fournis par une simulation sismique correspondante.

ZUSAMMENFASSUNG

Der Artikel stellt ein Schätzungsverfahren des Erdbebenschadens für mit Mauerwerk ausgefachten Stahlbetonrahmen vor. In der Analyse werden die Füllwände als gleichwertiges Fachwerk idealisiert. Für Stahlbeton und ausfachendes Mauerwerk werden Kraft-Verschiebungsbeziehungen mit abfallendem Ast vorgeschlagen. Pseudodynamische Versuche wurden mit on-line gesteuerten Kolbenpressen an zwei Modellen mit zwei Stockwerken und zwei Feldern durchgeführt. Die analytischen Ergebnisse für das elastische, inelastische und Grenztragverhalten liegen nahe bei denen aus den entsprechenden Erdbebensimulationen.

1. INTRODUCTION

Reinforced Concrete Frames with infilled brick walls have been extensively used in seismic areas in China. The changes of actions or conversion of existing buildings to new uses often require to determine the seismic behavior of such structures. Both laboratory studies and damage observation from past earthquakes indicated that the interaction of infilled brick walls with reinforced concrete frames had a significant influence on the performance of a brick-infilled frame. However, no consensus has yet emerged to provide a unified approach for either their seismic design or load-carrying capacity and ductility evaluation. Under the strong ground motion the internal forces and deformations of the structure are usually far beyond the linear elastic range. During a severe earthquake the members may come into descending branch and the structure will be in an unstable deformation state. The previous elasto-plastic dynamic analysis methods for the multi-degree of freedom system are based on the assumption that any element in structure cannot approach the load-carrying capacity or come tinto the descending branch. As a result, current dynamic collapse analysis of structure is actually restricted to the stage before the ultimate state. Because the structural element in the descending branch may make the structure to come into unstable state, seismic response of the structure in the unstable state should be greatly different from the normal elasto-plastic response. It is necessary to consider an unstable state in order to evaluate correctly the damage level, weak parts and collapse process of a structure under a severe earthquake. In an infilled frame structure, the brick walls restrained by the frame act as bracings with nonlinear characteristics. Because the existence of brick infilled walls elasto-plastic seismic response of whole structure is greatly different form that of the frame without brick infilled walls.

2. ANALYTICAL METHOD OF COLLAPSE EVALUATION

In analysis the following assumptions are used:

(1) It is assumed that the stiffness in the plane of the horizontal floor is infinite.

(2) Trilinear degradation shape is used for representing the characteristics of the restoring force of bending moment M and curvature Φ of reinforced concrete elements as shown in Fig.1. The descending branch is considered. The degradation of unloading stiffness and reloading stiffness after unloading is also considered.

(3) The influence of the bar slippage in joint on response of the structures is considered. The restoring force model of the slippage rotation spring at the end of the element is shown in Fig.2 [1].

(4) When the calculation bending moment M of element reaches the yielding moment My, the plastic hinge zone would be formed and concentrated at the ends of the element. The element can be considered as an element of variable stiffness with nonlinear spring which represents the slippage rotation at the end of element.

(5) The brick walls restrained by the frame act as bracings. In order to consider this interaction the brick infilled walls can be simplified as an equivalent bracing element. Based on the experimental results the restoring force model of the brick wall is suggested as shown in Fig.3 [2].

The horizontal displacement function W is assumed to be developed as following series:

$$W(s,t) = \sum_{i=1}^{n} T_i(t) f_i(s) \tag{1}$$

In Eq.(1) fi (s) is the horizontal unit displacement function, which describes the diagram of unit displacement of the structure and only relate with the coordination s. Ti (t) is the generalized displacement function and only relate with time t.
According to the principle of virtual displacements, the equation of the virtual work of the structural system under strong ground motion can be obtained as following:

$$\sum_{i=1}^{n}[m_{ji}\ddot{T}_i+c_{ji}\dot{T}_i+k_{ji}T]=q_i \tag{2}$$

where

$$\begin{aligned} m_{ji} &= \int_0^L mf_if_jds \\ c_{ji} &= \int_0^L cf_if_jds \\ k_{ji} &= \int_0^L \frac{M_iM_j}{EI}ds+\int_0^L \frac{Q_iQ_j}{GA}ds+\int_0^L \frac{N_iN_j}{EA}ds-\int_0^L N_gf_i'f_i'ds \\ q_j &= -\int_0^L m\ddot{W}_g f_jds \end{aligned} \tag{3}$$

and $\ddot{W}_g$ is the acceleration record of the ground motion, EI is the bending stiffness, GA is the shearing stiffness, EA is the compressive stiffness, m is the mass, c is the damping coefficient and Ng is the axial force due to the static loading. In Eq.(3), Mi(s), Qi(s) and Ni(s) are functions of unit bending moment, unit shearing force and unit axial force respectively. They describe the diagrams of internal forces developed under the unit displacement functions $f_i(s)$. The selection of the unit displacement functions can be arbitrary, but the relations among the unit displacement functions must be linear independent and they have to satisfy the boundary conditions. The numbers of the unit displacement functions would be determined by the degrees of freedom of the structure system. If the proportion of the response of higher modes is less in the total response of a structure system, the motion condition of the structure system under the strong ground motion can be well described by less items of the unit displacement functions. It should be pointed out that the structure will be in an unstable state as soon as the stiffness matrix of the whole structural system has any non-positive eigenvalue. The definition about the structure collapse under a severe earthquake may be represented as following: if the structure has been in unstable state and, at the same time, the ductilities of the structure approach concerned value, the structure collapses[3]. From this definition the unstable state of the structure is necessary condition for the structure collapse.

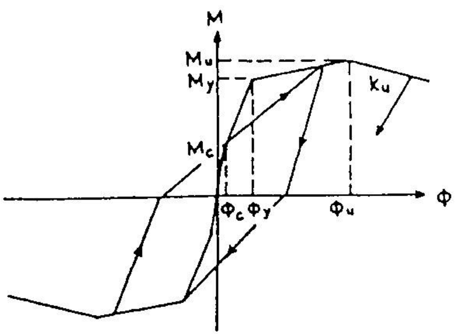

Fig.1

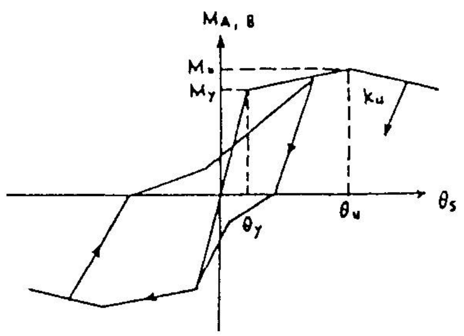

Fig.2

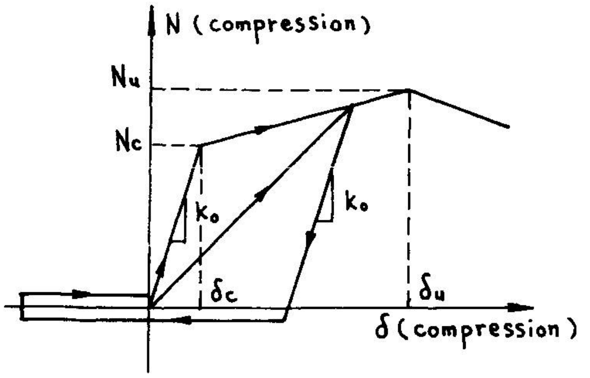

Fig.3

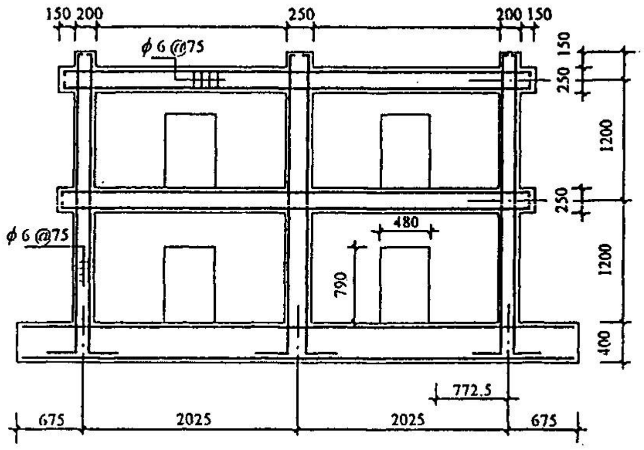

Fig.4

3. EXPERIMENTAL VERIFICATION BY PSEUDO-DYNAMIC TEST

In order to gain a better understanding of seismic behavior of brick-infilled reinforced concrete frames and to verify the mechanical model and analysis method, three frame models were tested by computer-actuator on-line system [4,5]. Three models with infilled brick walls fully, with in filled brick walls having openings and without infilled walls were made. Designations of three test models are used as FFW, FWO and FNW respectively. The dimensions of three models with two stories and two spans are in 1:2.5 scale of the prototype structure. Figure 4 shows the overall dimensions of the three models. The dimension of bricks is 120 × 57 × 53mm, which were cut out from normal bricks with dimension of 240 × 115 × 57mm. The sections of columns and girders are 20 × 20cm and 15 × 25cm repectively. Ground acceleration for earthquake simulation was modelled after the N-S component of EL Centro 1940 earthquake. Figure 5 shows the maximum base shear force of the three models in the different experiment stages. It can be seen from the figures that the differences in the seismic response of the three models are apparent and reasonable. For model FFW during simulation with peak base acceleration 0.2g the visible crack appeared in infilled wells. During simulation with peak base acceleration 0.4g, the cracks in infilled wall widened and developed toward the corner of the wall and connected to form major X shape diagonal crack, and the reinforcing bars in the middle column of the first story yielded with

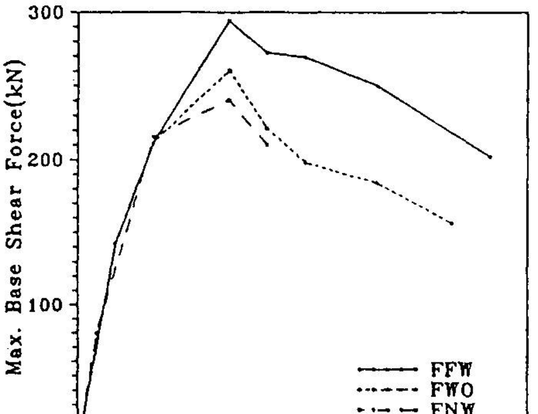

Fig.5

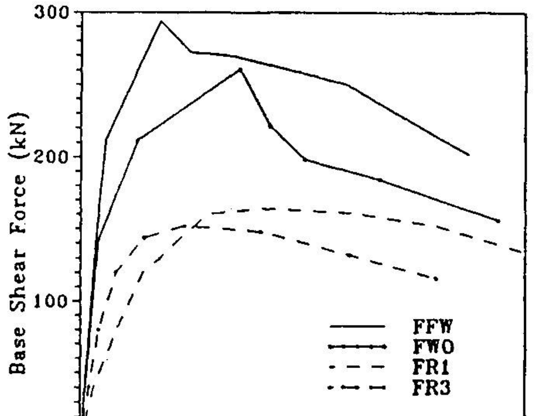

Fig.6

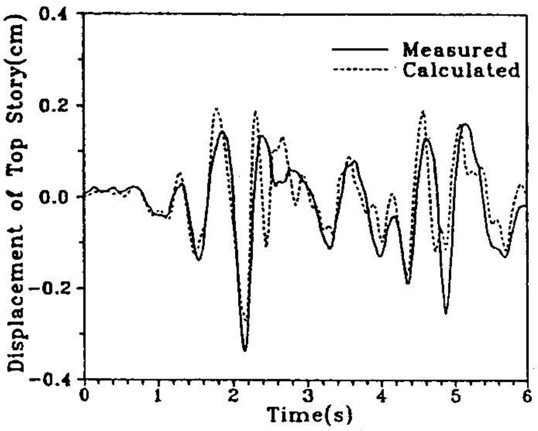

Fig.7 Elastic Response (A_{max}=0.1g)

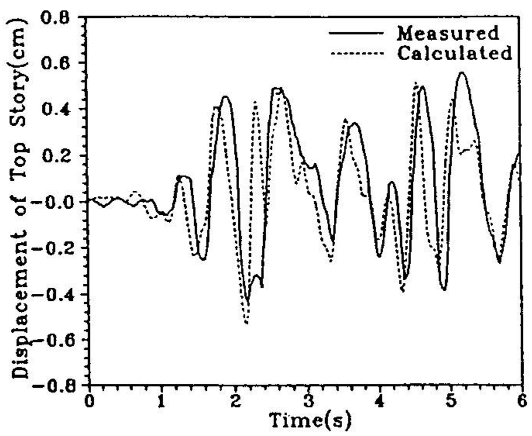

Fig.8 Inelastic Response (A_{max}=0.2g)

great decrease of the structure stiffness so the structure reached yielding stage. During simulation with peak base acceleration 1.1g the structure suffered a serious damage in the first story, but the top story suffered much less serious damage. For model FWO during simulation with peak base acceleration 0.2g the previous cracks developed toward the corner of infilled walls and the X shape diagonal cracks formed in both sides of openings. During simulation in which peak base acceleration were 0.4g and 1.0g respectively, the structure reached yielding stage and failure stage respectively. The most serious damage occurred around openings and at the ends of columns in the first story. The load-carry capacity of model FNW is much less than that of models FFW and FWO. Fig.6 Shows the measured relation between base shear force and top displacement for models FFW, FWO, FR1 and FR3 in different experiment stages. The models FR1 and FR3 at same size with models FFW and FWO were tested by quasi-static method [6]. The model FR1 and FR3 were designed as a strong column-weak beam type and strong beam-weak column type without infilled walls respectively. The damage and deformation of FWO was more serious than that of model FFW.

The measured and calculated time-dependent curves of displacement for model FFW during simulation with peak base acceleration 0.1g and 0.2g are shown in Fig.7 and Fig.8 respectively. Figure 9 shows the measured and calculated time-dependent curves of displacement for model FFW during simulation with peak base acceleration 1.1g. The calculated curve is obtained by inelastic analysis with consideration of descending branch. It is indicated that the experimental and analytical results in elastic, inelastic and collapse earthquake response are in good agreement.

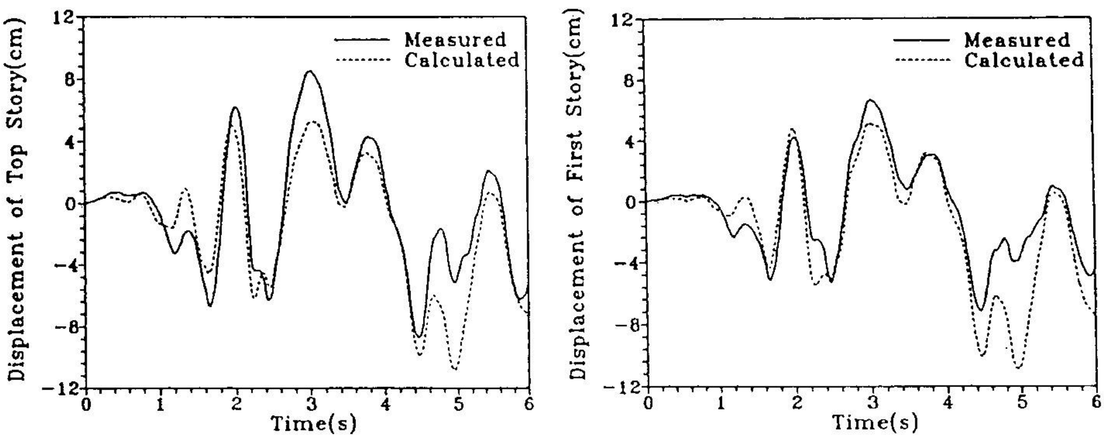

Fig.9 Collapse Response (A_{max}=1.1g)

4. CONCLUSIONS

1. From experimental and analytical results it is shown that due to the existance of the infilled brick walls the initial stiffness and load-carry capacity of a frame obviously increase, but the deformation capacity and ductility of both frames with or without infilled walls are nearly same. The inelastic earthquake response of whole structure with infilled brick walls is greatly different from that of the frame without infilled brick walls.
2. The plastic hinges of a brick infilled frame may appear at the ends of columns under strong ground motion.
3. The measured and calculated time-dependent curves of displacement of infilled-brick frame without openings, whether in the elastic stage, inelastic stage or in failure stage after the structure comes into the unstable stage, are all in good agreement. It is indicated that the mechanical models, restoring force model and calculated method in analysis are reasonable.

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