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Seismic Strengthening of Structures

Renforcement des structures contre les effets sismiques

Seismische Verstärkung von Tragwerken

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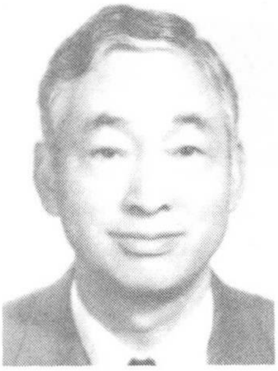


Zhixin Xu, born in 1929, received his B.S. degree in civil engineering at Jiaotong University, Shanghai, in 1949. For thirteen years he served in a structural design office. He completed his graduate study at Tongji University in 1964. Since then he has been professor at Tongji University.

SUMMARY

Methods of seismic appraisal and strengthening are presented. Firstly the level of seismic resistance is addressed. It is determined through specific study for important structures and by following code for ordinary structures. The author emphasises his view that the same safety requirements are preferable for residential and public buildings. Three cases of seismic strengthening including public buildings and important hazardous structure are presented.

RÉSUMÉ

L'auteur présente des méthodes d'évaluation et de renforcement de structures vis-à-vis des tremblements de terre. Il définit l'importance du niveau de résistance parasismique au moyen d'études spéciales pour des constructions importantes et de règles pour les constructions habituelles. L'auteur estime que les immeubles d'habitation et les bâtiments publics devraient satisfaire aux mêmes exigences de sécurité. Il présente trois exemples pratiques, permettant d'améliorer le comportement aux effets sismiques des bâtiments publics et à haut risque.

ZUSAMMENFASSUNG

Es werden Verfahren zur Beurteilung und Verstärkung gegenüber Erdbeben vorgestellt. Zuerst wird das erforderliche Niveau der Erdbebenvorkehrungen angesprochen, das sich aus speziellen Studien für wichtige Bauten und Normenbestimmungen für gewöhnliche Bauten herleitet. Nach Meinung des Verfassers sollten Wohnbauten und öffentliche Bauten die Sicherheitsanforderungen für heutige Neubauten erfüllen. Drei praktische Beispiele für die seismische Ertüchtigung öffentlicher Bauten und wichtiger Risikotragwerke werden aufgeführt.

1. INTRODUCTION

It is not unusual that the seismic hazard of a region is identified later higher than the previous assigned level. Seismic strengthening has to be implemented in order to keep buildings and structures safe during future earthquake. During 1966 to 1976 three destructive earthquakes took place in Xingtai, Haicheng and Tangshan. These regions were zoned then as region of fundamental intensity VI in Chinese scale which is almost equivalent to MMI. The epicentral intensity of Tangshan earthquake is XI. For other two earthquakes,the epicentral intensity reaches IX. Since then seiemic hazard of many cities has been reassessed, and fundamental intensity of many a city has been raised. Among them is Shanghai where the fundamental intensity is raised to VII from the original VI. A large scale of seismic appraising and strengthing has been being carried out for various buildings and structures in these regions. The author has been being involved in seismic appraising and design of strengthening. Some important features regarding these works are presented here.

2. LEVEL OF SEISMIC PROVISION

The first problem of seismic appraising and strengthening is the level of seismic provision. This of course depends on the seismic hazard of the region. The seismic hazard of a region is assessed in China mainly by means of the method similar to those proposed by Cornell[1] and Ang[2]. The main points are as follows. For causative faults or areas near a site the probability of occurrence of earthquake of various magnitude is identified. Poisson process is usually adopted for simplicity. Richter's formula for magnitude distribution is used. Also assumed is that the rupture length is related to the magnitude of an earthquake which can take place everywhere along the causative fault,thus the shortest distance from the rupture to the site can be determined. Using some attenuation relationship which defines the ground motion as a definite function of magnitude and rupture distance the seismic hazard of a site is assessed. The result is the values of a certain ground motion parameter,usually maximum acceleration corresponding to various probability of exceedance within a certain period of time.

Theoretically the optimal seismic level of strengthening can be determined through minimization of total cost

$$C_t(a)=E[L(a)]+S(a)$$

where E[L(a)] is the expected earthquake loss under ground motion with maximum acceleration a, S(a) is the cost of strengthening, both reduced to present value. Actually such optimization can hardly be conducted not only due to time consuming but also less reliablity, since both the probability of occurrence of the maximum acceleration and the loss can only be assessed very roughly and with low reliablity.

The practice in China is that for appraising and strengthening the level of seismic provision is specified somewahat lower than designing a new one. For example, the seismic appraising standard (draft) specifies that the earthquake resistant strength can be 15% lower than the design code requirement for reinforced concrete structure and steel structure. For masonry structure the standard specifies that the required strength of brick wall in region of intensity VIII and IX is 1.5 and 2.5 times that required in region of intensity VII. It is obvious that the safety level for appraising in region of intensity VIII or IX is much too low since the earthquake action in these regions is twice and four times that in region of intensity VII. In the author's view deliberately lowering the safety requirement is inadvisable. Unless careful study is conducted the same safety level as design code is preferable.

3.METHOD OF APPRAISING AND STRENGTHENING

3.1 Masonry building

This type of building is the most vulnerable during earthquake and is the most frequently used for residential buildings in China. The main features determine the earthquake resistant capacity is the layout, regularity of plane and elevation , cross sectional area of transverse and longitudinal bearing walls, height, quality of brick, mortar and construction, width of pier between windows and at corners, bearing length of slab and roof, arrangement of tie beams and so on. According to appraising standard (draft) the seismic resistant capacity is expressed as

$$\beta_{c_i}=\frac{A_i}{A_{b_i}\xi_{o_i}\lambda}\psi_1\psi_2$$

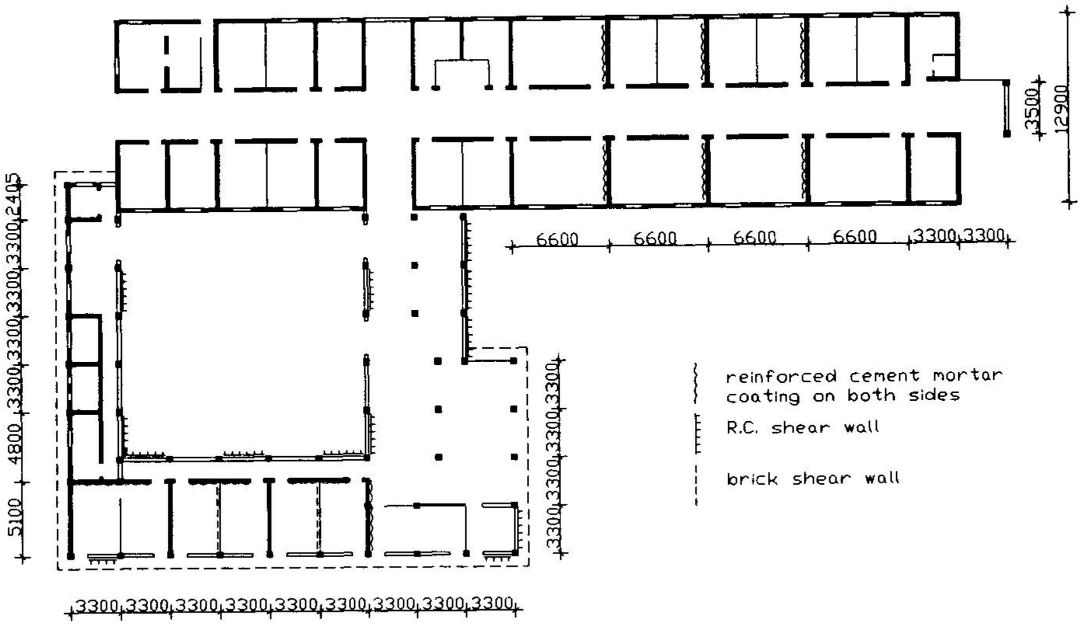
If the smallest value of β_{ci} for the weakest storey,weakest sector is larger than 1, the building is evaluated as safe. A_i is the net cross sectional area of transverse or longitudinal walls at half storey height of i-th floor. A_{bi} is the floor area of i-th floor. ξ_{oi}, an empirical coefficient depends on mortar strength, number of floor level and storeys. λ=0.7,1.0,1.5 and 2.5 for regions of seismic intensity VI,VII,VIII and IX respectively. ψ_1 is a coefficient taking care of the layout and construction quality, ψ_2 ,a coefficient taking care of details.
As has been pointed out by the author, λ is inadequate . The author uses the safety criterion given in the Design Code,which specifies

$$V\leq\frac{R}{\gamma_{RE}}$$

where V is the shear due to earthquake excitation, R is the shear strength of the wall, γ_{RE} is a coefficient considering the increase of allowable strength for earthquake loading.
In selecting strengthening method, effectiveness, reliablity and influence to occupants and normal use have to be considered. This is important for all kinds of structure. The methods of strengthening masonry building commonly used consist of cement grouting, coating with plain or reinforced mortar, constructing shear wall, installing reinforced concrete rigid frame surrounding the building.The last method is the most effctive one against collapse. Its effectiveness has been verified by shaking table test at Tongji[3].Three six storey cinder block masonry

buildings one of which was strengthened by columns at corners and every transverse wall and tie beams at alternate floor levels were tested. The result showed that the strengthened building collapsed under a_{max}=0.45g, while the other two collapsed at a_{max}=0.36g and 0.3g. The crack initiated at 0.13g and 0.07,0.09g.

Case 1
Xianhe is a city in Shandong Province where the fundamental intensity was reassessed as VII from the original VI. Almost all the buildings in the city belong to Gudong Petroleum Company. Here the strengthening of Administration Building of Gudong Petroleum Company is shown in Fig. 1. The strength of mortar was determined by test on specimen cut from wall. The appraising of this building showed defects in some wall sectors in the main building and serious defects in the wing. Constructing shear wall and coating weak wall sector with reinforced cement mortar were used.



(length in mm)

Fig.1 Strengthening of brick masonry building

3.2 Reinforced Concrete and Steel Structures

The Appraising is carried out by visual inspection and analysis. The layout, configuration of plane and elevation, supporting condition of beam, truss, bracing system, connection of nonstructural member can be appraised by visual inspection. The seismic response and the safety of the structure to be calculated in the same way as for a newly designed structure is advisable. The strengthening of reinforced concrete member can use jacketing, strengthened by steel angle or plate, changing structural system by inserting lateral resistant frame, shear wall or bracing system. In doing so care has to be taken that the strengthening system can share the existing load when necessary. Appraising and strengthening steel structure is much the same as for reinforced structure. It is more convenient and easy to strengthen a steel structure than a reinforced concrete one.

Case 2
Baoshan Stadium is a stadium for audience of three thousand. The roof is of precast reinforced concrete slab putting on steel grid structure. Four rows of columns and plateform girders form a rigid frame supporting the grid. Columns in row A are for decoration (Fig. 3). The strengthening to withstand intensity VII was implemented in early ninties. Seismic response analysis revealed that columns in row B and row E do not have sufficient strength. Inspection showed that the support length of roof slab is too short and the dormer window struts are not well braced. Three options of strengthening had been considered: connecting columns in row A and row B to form a frame, strengthening columns in row B and inserting bracing between columns in row D and row E. The first option would destroy the architecture . The last option would cause inconvenience in use and also too rigid the bracing system would be resulting in irregularity of rigidity. Finally columns in row B were strengthened by increasing the section and reinforcement of the column. The stress in columns in row D was thus decreased and no strengthening was needed. Accessaries to improve the supporting condition of roof slab and bracing at dormer window were added.

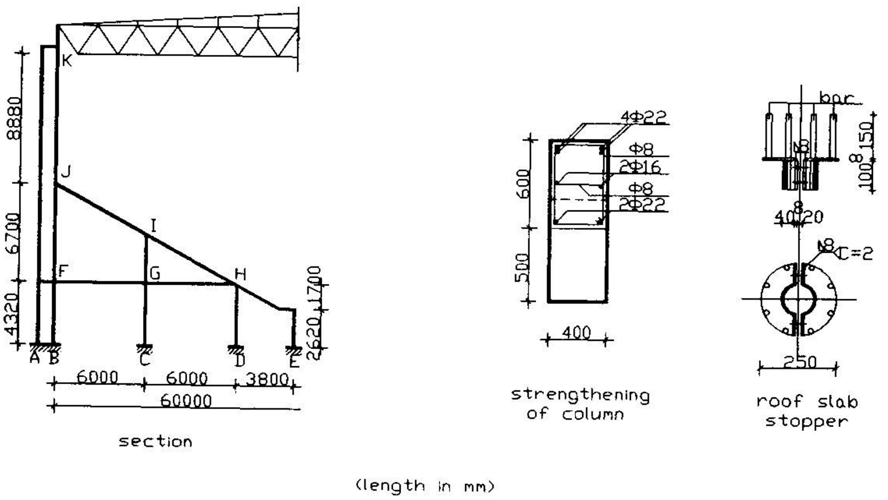


Fig.2 Strengthening of reinforced concrete structures

Case 3
There was no seismic provision for the main pipeline in Shanghai Baoshan Iron and Steel Company during construction. The intensity of site was reassessed as VII according to a specific study. The design response spectrum was also given by that study. In appraising the pipeline was modelled as beam element taking consideration of all the expansion joint, connection and other accessaries. The support was modelled as a spring of six components and three components for rigid support and hinged support respectively. Modal superposition method was used for

seismic response analysis at least twenty five modes being considered. The sum of absolute value of response of modes with natural frequency differing within ten percent was taken and combined with other contributions by means of SSRS. The contributions from the excitation of three directions were combined also by means of SSRS. According to Chinese code, the allowable tensile stress for steel is $[\sigma]=\sigma_u/3=134$Mpa for long term load. A structural factor c=0.3 was apllied to support only that the pipe itself would not yield even under earthquake action.
Several unsafe pipe sectors were discovered.One is shown in Fig.3, where pipe dilivering CO runs in a very complicated way and with unsupported length 40m. The maximum stress (stress concentration considered) at four sections was 465 Mpa to 485 Mpa due to dead load only. Stress due to dead load and earthquake was 544 Mpa to 556 Mpa. The solution was an additional support which raised the pipeline during construction to take reaction from the dead load. The maximum stress was reduced to 76 Mpa (dead load) and 155 Mpa (dead load + earthquake).
Anchor bolts in two fixed rigid frame type support will be overstressed under earthquake. The solution was to insert diagonal members changing the support to a truss. The bending moment of the vertical members was eliminated and thus the tension in anchor bolts was reduced magnificantly.

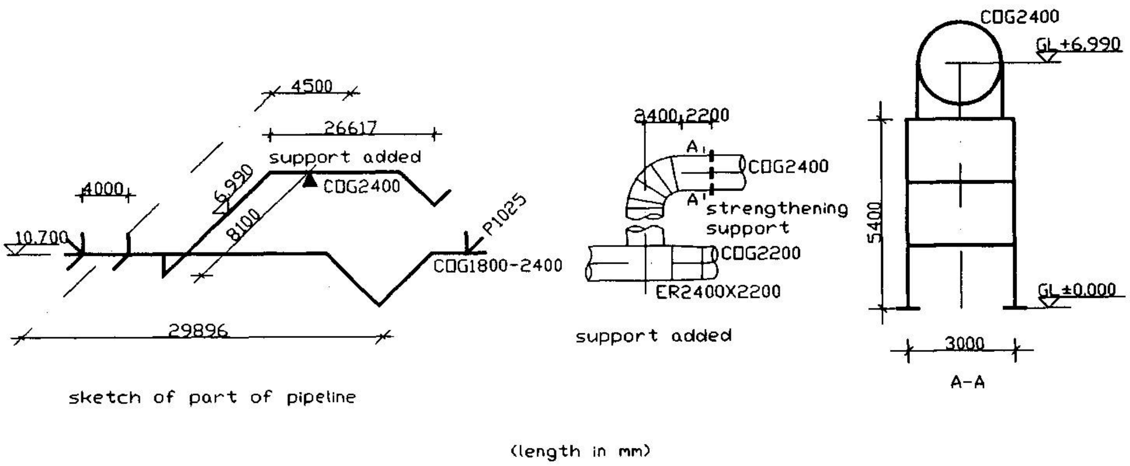


Fig.3 Strengthening of steel pipeline

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