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Study on Interactive Computer Program for Seismic Appraisal and Seismic Strengthening of R.C. Frame Structures

Yin Jie[1*] Liang Shuting[1] Jiang Yongsheng[1] Yin Guihong[2]

([1] The Key Laboratory of R.C. & P.C. Structures of Ministry of Education, Southeast University, Nanjing 210096, China)
([2] Yantai Supervision Station of Constructional Engineering Quality, Yantai 264000, China)

Abstract: In many cases, seismic appraisal of existing structures is carried out by the two-step method and seismic strengthening of R.C. frame structures is solved just based on rough calculation or experience of designers, which may lead to either lack of safety or too conservative in design. According to some related criteria and experts' experience, a computer program is developed specially for seismic appraisal and seismic strengthening of R.C. frames (not more than 10 storeys) in this paper. Because the program has a friendly interactive interface and a "navigating" function, users with a little knowledge of civil engineering can use the program to finish the job of seismic appraisal and seismic strengthening of R.C. frames. After seismic appraisal is completed, three strengthening methods can be selected, which are increasing the components' section with reinforced concrete, encasing them with angle steel and adhering steel plate on their surfaces, respectively. The design work based on the program will be completed more accurately, reasonably and quickly. At the same time, a great deal of manpower, material resources and financial resources can be saved.

Key words: adhering steel plate, bonding angles steel, jacketing with R.C., seismic appraisal, seismic strengthening

With the development of national economy and the extension of earthquake knowledge in China, a large number of existing buildings built in 1950s or 1960s are poor of seismic performance and don't comply with current national standards. They need rehabilitation (pre-earthquake rehabilitation or post-earthquake rehabilitation) to meet the requirements of the standards after seismic appraisal. In China, R.C. frame structures play an important role in industrial and civil buildings. However, investigation results of post intense earthquakes indicate that some frames are seriously damaged and some even collapsed. Building collapse and fire were the main causes of death. At the same time, a few cases of extensively rehabilitated buildings, which experienced strong ground motion after rehabilitation, were reported that they did not suffer severe damage while some others did in the same area. Thus, the importance and effectiveness of seismic rehabilitation have been recognized year after year[1].

Although the seismic strengthening is important, it is more complicate and troublesome than construction of new buildings for architects and engineers. There are some national standards for seismic appraisal and seismic strengthening, such as "Standard for Seismic Appraiser of Building" and "Technical Specification for Seismic Strengthening of Building", but all of them are not convenient for practical use. Engineers have to calculate mainly by hand to evaluate the seismic capacity of a building before and after strengthening. Based on the standards mentioned above and experts' experience, a computer program is developed specially for seismic appraisal and seismic strengthening of R.C. frames in this paper. The strengthening scheme can either be recommended by the program or be given by engineers. The design work based on the program will be completed more accurately, reasonably and quickly. Three strengthening methods can be selected in the program. They are traditional seismic resistance techniques that have been supported by experimental research and widely used in practice. Some modern techniques, such as seismic isolation and supplemental damping, are difficult in design and not adopted by the current national standard[2].

1 Difficulties and Countermeasures of Seismic Strengthening

There are a lot of difficulties in designing and strengthening an existing frame structure.

Firstly, seismic strengthening must be carried out on the basis of exact values of internal force and bearing capacity of components, but engineers cannot get these data by the two-step method recommended in

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* Born in 1975, male, graduate.

the seismic appraisal standard. According to the standard, engineers should evaluate the seismic capacity from the viewpoint of macro-control and micro constructional details of the frames in the first step. If all requirements are met, the frame is judged to have good seismic performance. Otherwise, engineers should calculate the seismic composite index β in the second step. If the index β is larger than 1.0, the frame is eligible[3]. In practice, even if a frame is eligible by the two-step method, the strength of some components may be not enough because they are not calculated exactly. Without these data, the frame won't be strengthened properly.

Secondly, if a frame is strengthened improperly, some components which are safe during the initial appraisal may be unreliable after the strengthening. The strength, stiffness and mass of the strengthened members are all modified and the seismic performance of the strengthened frame is changed. Thus, the redistribution of the design earthquake force is inevitable. New weak storey may occur. Such phenomenon can be defined as "transfer of latent danger".

Thirdly, unloading or not will affect the performance of strengthened frames. The newly added part of an unsafe member can't fully exert its potential capacity with the previous parts, because its stress and strain are lower than that of the existing part. If the stress and strain of the previous frame is high before strengthening, the previous part will fail before the added part function effectively. On the contrary, if the frame is unloaded sufficiently, the two parts will work together and fail simultaneously and the ultimate strength of strengthened members will be increased significantly. This view has been supported by experimental research[4].

Thus, the seismic strengthening is so complex that it is usually solved just based on rough calculation or experience of designers, which will lead to either lack of safety or too conservative in design. The following countermeasures are taken into account in the program.

After the first step of the initial appraisal, designers can use this program to calculate the seismic composite index and the exact values of strength. The safety of each component is judged by

$$S \leqslant R/\gamma_{Ra} \tag{1}$$

where S is the internal force in components; R is the bearing capacity of components; and γ_{Ra} is the coefficient of bearing capacity. The next design of strengthening is based on these data.

The program will calculate the new strength, stiffness and mass of the strengthened members and use these data to evaluate the strengthened frame again, which is defined as "reappraisal". The reappraisal can find out all unreliable members and strengthen them, so that the transfer of latent danger will be avoided.

In order to make full use of the added materials and ensure that the seismic strengthening is successful, the unloading must be carried out. In the program, the unloading index φ is introduced. The index φ is evaluated as a ratio of the load after unloading F_u and the previous design load F_0:

$$\varphi = F_u/F_0 \tag{2}$$

Once the reinforcement's stress exceeds $0.6\ f_y$ (where f_y is the yield strength of reinforcement in unsafe components) in the initial appraisal, the program will stop and warn the user to unload as much as possible. Otherwise, the program won't go on.

Therefore, the computer program can ensure that the seismic strengthening is effective. Designers will complete the seismic strengthening in a few hours without manual calculation.

2 Development of Interactive Computer Program

The objects of the interactive computer program are to evaluate the seismic performance of existing frames, to strengthen unsafe components, to reappraise the strengthened frame, and to draw abridged general views. The development of the computer program can be divided into three stages. (The flow chart is shown in Fig.1.)

In the first stage, a friendly interactive interface is developed. It is important for software application. The program not only has some help functions and error-correcting ability, but also has a "navigating" function, which means that if the user inputs some unreasonable or wrong data, or runs the program in unsuitable order, he will get warning information at once and then be guided to take proper measures. In addition, after initial appraisal the program will advise the user not to select the unreasonable method. For instance, if the flexural strength is not adequate because of the lack of reinforcements at the end of a beam, the better scheme is to strengthen with R.C. at its top, not at the bottom. The user can modify the strengthening scheme recommended by the program, and the program will reappraise the frame with the data given by the user.

In the second stage, a series of equations are

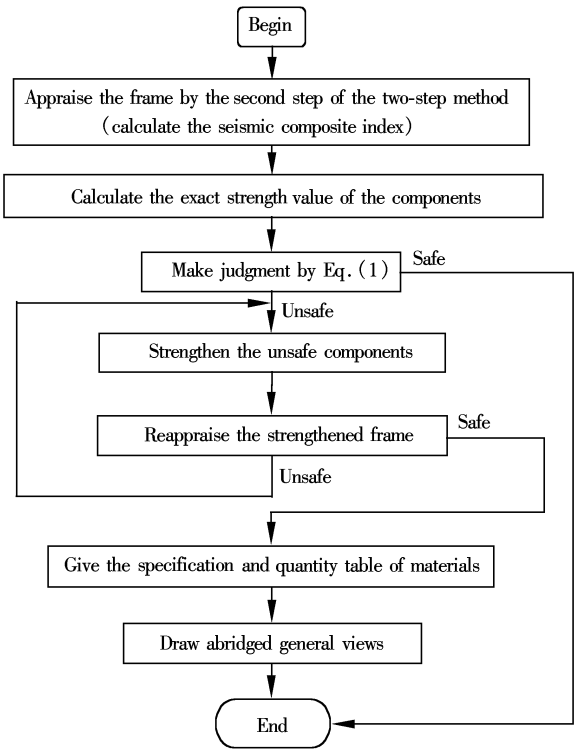

Fig. 1 Flow chart of the program

established to evaluate the flexural strength, shear strength, and stiffness of the strengthened components, which is a little different from and more complex than that in current standards. But the hypotheses of them are nearly the same.

In the third stage, a table of the specifications and quantity of materials used in three methods will be listed. The user can compare the methods and select the best scheme with the help of the table. Abridged general views will be drawn at last.

These stages are not separated distinctly and they are assembled together.

3 Conclusions

Based on the research reported here, the interactive computer program for seismic appraisal and seismic strengthening of R.C. frame structures has the following advantages:

1) A structural engineer can use the program to appraise and strengthen frames in a few hours without any manual calculation;

2) The reappraisal can find out all unreliable components of the strengthened frame and strengthen them;

3) The transfer of latent danger will be avoided.

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钢筋混凝土框架抗震鉴定与加固程序开发

殷 杰[1] 梁书亭[1] 蒋永生[1] 尹贵宏[2]

([1] 东南大学混凝土与预应力混凝土结构教育部重点实验室,南京 210096)
([2] 烟台市建筑工程质量监督站,烟台 264000)

摘 要 现有结构的抗震鉴定采用两级鉴定法,设计人员往往根据粗略计算和经验进行加固,导致加固方案不安全或过于保守.本文依据有关国家标准及专家经验,编制了钢筋混凝土框架抗震鉴定与加固计算机软件.该软件具有"导航"功能,人机界面友好.具有一般土建知识的用户即可通过使用该软件选用加大截面法、钢构套法或粘钢法对钢筋混凝土框架进行较准确、合理、快速的抗震加固设计,并节省大量的人力、物力和财力.

关键词 粘钢法, 钢构套法, 加大截面法, 抗震鉴定, 抗震加固

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