Seismic Assessment of electric power transmission concrete beams

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Abstract

Reinforced concrete beams are widely used for transmitting electric power in urban environment in some countries like IRAN. In this paper, one kind of these RC beams are investigated and optimized. The available section can sustain lateral forces much more than necessary that's why the need for optimizing the section seems essential. To achieve the optimized section, nonlinear programming is carried out by the use of analytical formulas from ACI. After that, the adequacy of the beam is checked by the use of pushover analysis. Finally, to obtain the actual behavior of the proposed sections, three specimens are constructed and tested. According to the provision for accepting these beams, a concentrated load should be exerted at the top of the beam and monotonically increases to obtain the pushover curve of the beam. Displacements at the top of the beam should not exceed certain values at different levels of load. Here, first of all, a new reinforcement arrangement is proposed for the beam based on nonlinear programming. After that, the adequacy of proposed reinforcement will be checked by the means of pushover analysis. Finally, three beams with proposed reinforcement arrangement are built and tested. The final results of all of the constructed beams satisfied the provisions, hence can be used in practice.

Introduction

In some countries like IRAN, concrete beams are used for holding the wires to transfer electric power in urban environment that, first the height of the wires are not necessarily high and second the space occupied by each holder minimized. Figure 1 illustrates one kind of these concrete beams in urban environment.

Figure 1- Cantilever reinforced concrete beam for transmitting electric power in urban environment

On the other hand, these beams are also in various lengths and dimensions respect to the location they are used. In this paper, one of the most popular beams used in the middle of an electric line is investigated. This kind of beams should sustain a force at the top of them in allowable elastic range equal to 200 kgf (the actual elastic capacity of these beams should be ($200 \times SF$) where SF is safety factor) and has 9 meters long (that's why they are called 9/200 beams). The test is shown in fig. 2-a.

a) the pushover test

b) Ultimate scheme of the plastic hinge

Figure 2- Pushover test on the cantilever beams a) the whole test b) the cracked section due to the yielding of reinforcement

Using factor of safety equal to 1.67, the elastic strength of these beams is 334 kgf. It means that these beams should turn back to their original state after removing the force because they experience such magnitude force several times in their service life. In addition to elastic provision for these beams, they are also expected to sustain a force equal to 600 kgf in their ultimate capacity at the top of them to ensure the reliability of the line in severe earthquakes or strong winds. The later force is just needed prior to collapse of the beam.

The typical scheme of these beams and the reinforcements are shown in figure 3 and figure 4.

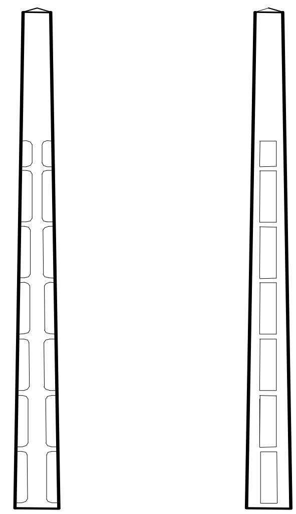

Figure 3- Typical scheme of the concrete beam

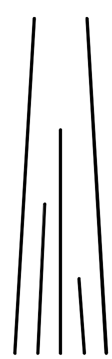

Figure 4- The reinforcement arrangement of the current beam

Optimizing the reinforcement

To obtain the optimized arrangement for the reinforcement, following standard form is used to minimize the objective function.

$$\begin{cases} \min f(\{X\}) \\ H(\{X\}) = 0 \\ G(\{X\}) \leq 0 \end{cases}$$

In the above, the function f is the objective function that is to be minimized and here it stands for the amount of longitudinal reinforcement. Equal conditions are $H(\{X\})$ that should be satisfied after solving the system. Equilibrium equations are categorized in these conditions. On the other hand, there are some more conditions that should be less than specific values, most code provisions and serviceability requirements are in this category (ACI318-02).

To establish the optimized system and find the optimized response, following assumptions are considered here:

1- Objective function is the amount of the longitudinal reinforcement or the weight of the reinforcement in the beam

2- The ultimate capacity of the beam is more than 600 kgf

3- The yielding force of the beam is more than 334 kgf

According to the dimensions of the beam, the objective function is chosen to be:

$$f(\{X\}) = 2 \times A_1 \times 900 + A_2 \times l_2 + A_3 \times l_3 + A_4 \times l_4$$

Parameters A_1, A_2, A_3 and A_4 are used instead of the sectional area of the bars and l_2, l_3 and l_4 stand for their length in the beam, it is obvious that at least one bar should be as long as the beam and because of the need for existing at least one bar in each corner of the section, the number 2 exists. In this function the volume of the longitudinal reinforcement is used as the target to be minimized. The procedure used for optimizing is based on iterative Newtonian procedures (Haftka 1992, Rao 1978). The available subroutines in FORTRAN are used to solve the nonlinear programming.

Finalizing the optimized response

Some more conditions should be taken in to account in finalizing the optimized response, the available length of the bars is one of them, in the other words, since the length of the bars is 12 m, length of the used bars should be such that the amount of the wasted bars approaches zero. In the proposed reinforcement arrangement there is not any wasted bar. The final scheme of the reinforcement is illustrated in figure 5.

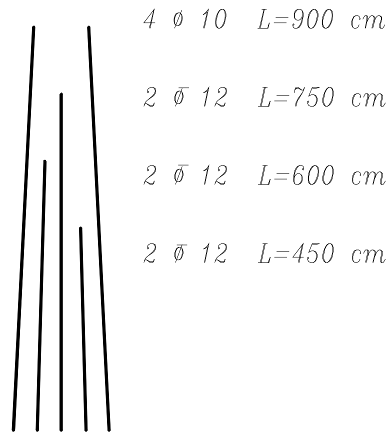

Figure 5- Proposed reinforcement arrangement

Pushover Analysis

Before constructing the beams, pushover analysis is carried out to approve the ability of the proposed reinforcement arrangement. To perform pushover analysis SeismoStruct (Computer code based on Finite Element Method) is used (SeismoSoft 2004). Bar properties are assumed to be elastic perfectly plastic with yield strength equal to $\sigma_y = 4000\ {kgf}/{cm^2}\ (400\ MPa)$ and modulus of elasticity equal to $E = 2.05 \times 10^6\ {kgf}/{cm^2}\ (200\ GPa)$. These qualities were approved by uni-axial test of the available bars. On the other hand, Concrete was assumed to have compressive cylindrical strength equal to 30 MPa.

SeismoStruct is a fiber based program to model the behavior of sections and elements and uses gauss points to calculate the needed integrations. Therefore, to achieve a reliable response, elements should be divided into small parts, especially in sections which longitudinal reinforcements change. Although confinement can be taken in to account, but since the distance between shear reinforcements are not enough close, the effect of confinement over the strength of the concrete is ignored.

The load-deflection curve obtained from nonlinear static analysis is illustrated in Fig. 6. As can be seen from the graph, the elastic bearing capacity and ultimate bearing capacity of the proposed beams are satisfying; it means all of the required provisions are satisfied.

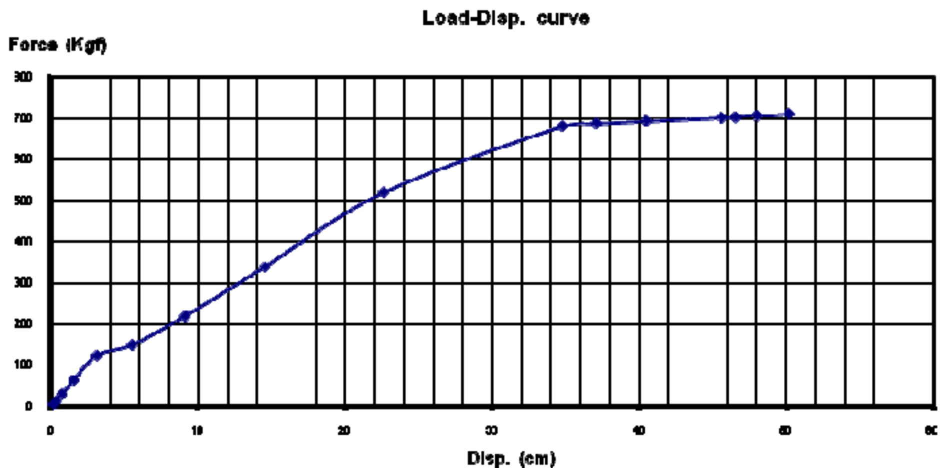

Figure 6- Predicted behavior of the proposed beams via SeismoStruct

Test response of the proposed beams

After constructing beams with the proposed reinforcement arrangement, the test was carried out. To achieve this goal, load and deflection in various levels were recorded. All of the beams were accepted with a minor increasing in capacity respect to acceptance criteria. In addition, it is seen that the elastic deflection of the beam is reduced. Following figures illustrate the behavior of the tested beams via the predicted (expected) behavior by finite element analysis.

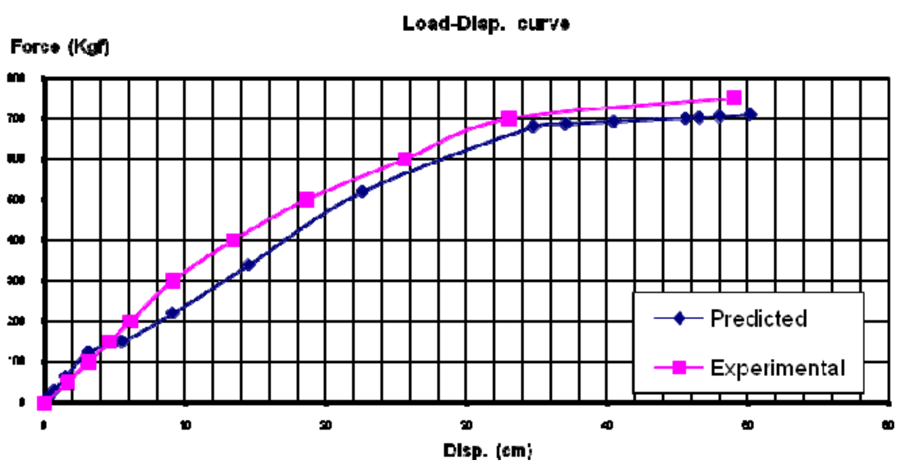

Figure 7- Predicted and experimented behavior of new beams

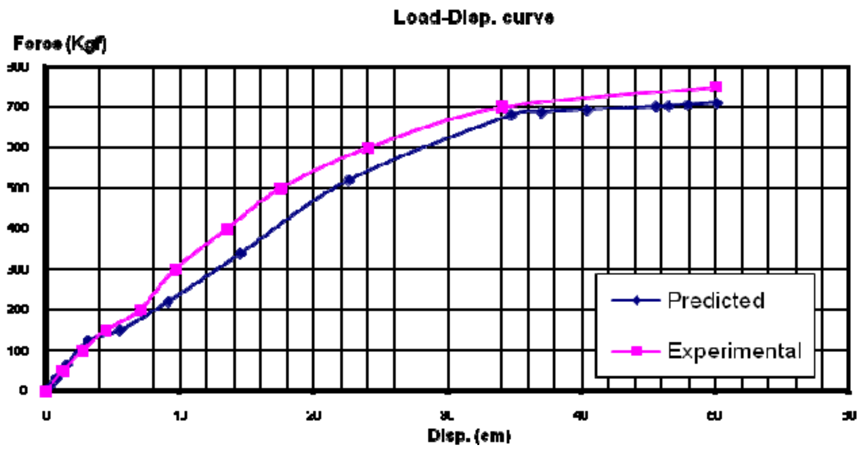

Figure 8- Predicted and experimented behavior of new beams

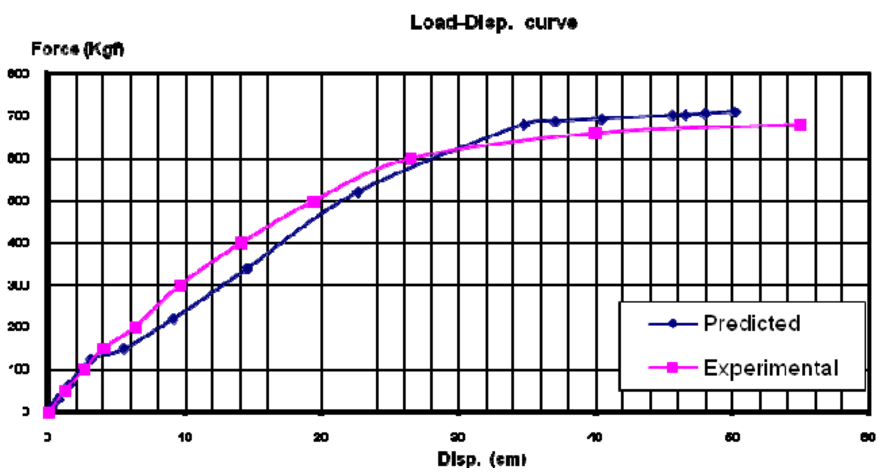

Figure 9- Predicted and experimented behavior of new beams

Comparison of the old and proposed beams

As was seen before, even though the amount of reinforcement in the beams is reduced, they can sustain the predefined criteria in the associated test. The volume of the reinforcement in old beams is $V_1 = 9236\ cm^3$ in each beam. The volume of the reinforcement in proposed beams is equal to $V_2 = 6895\ cm^3$. Therefore, the percentage of the reduction in reinforcement in each beam is about 25% in a way that the expected behavior of the beams remains acceptable.

Conclusion

Based on nonlinear programming, optimization on the reinforcement of concrete beams used in transmission electric power was carried out. After that, pushover analysis was used to predict the more realistic behavior of the proposed beams. Since the behaviors of the proposed beams were satisfying, three specimens with the proposed reinforcement arrangement were constructed. After 28 days, the acceptance test was carried out to investigate the actual behavior of beams with the proposed reinforcement arrangement. The actual behaviors of the constructed beams were near to that were predicted by pushover analysis. It means that, the proposed reinforcement arrangement can be used instead of the previous arrangement. The amount of the reduced reinforcement is considerable especially because of the need to construct a large number of these beams.

Acknowledgment

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