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Seismic Response of the Reconstructed Piers and of the Collapsed Pilz Piers

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Abstract

During the Hanshin Great Earthquake so many types of failure and collapses occurred in different types of structures. For the simulation of behavior of some failed and collapsed RC structures during the Kobe Earthquake, the authors have already developed a computer program using Distinct Element for Fracture Analysis (DEFA). In the developed numerical simulation the structural medium is modeled as an assembly of circular (disk) particles which are connected to each other through two types of springs and dash-pots (Voigt-Kelvin visco-elastic model). The force is transferring due to the concrete and reinforcement between those elements that are within a specified distance from each other. The general idea for using pore springs (regarding the contact springs in original DEM) in continuous media was introduced by Iwashita as the winkler types springs for modeling the cohesion.
The main concept for modeling the reinforcement is to consider the reinforcement as an additional spring-dash-pot between the concrete elements. The average area of the reinforcement can directly be considered as the area of additional (in addition to the concrete pore) pore between the related elements with the same properties of reinforcement. These two pore media between two elements are calculated and checked for failure criteria separately. We named this concept as the double-pore springs-dash-pots.
One of the most complicated and very rare failure cases during the Kobe Earthquake was the collapse of a group of Pilz (German language) piers (pier No.126 to No. 142) in Kobe Route of Hanshin Expressway. Construction method of this group was different from the other piers in their neighborhood. The collapsed segment was of Pilz construction in which the deck, girder and column were built together as a continuous system. In the section of longitudinal bars, amount of the bars reduced for the upper part and new bars were welded to the bars of lower part. There was also a time-gap for concrete placement for the lower and upper parts in this section.
According to these features, we selected the pier No. 126, which was the tallest one and located at the end part of the group from Kobe to Osaka Cities. To have rough estimation of the effect of bar cut-off section and time gap of concrete placement, the cohesion and tension strength are decreased in that section. We assumed two more cases for the analysis, considering the weakness of material and amplification of ground motion as two possible reasons of the collapse. Therefore, we analyzed 3 cases. In case one the concrete properties and one of the most sever acceleration records during the Kobe earthquake are input. In second case it is assumed that the concrete were weaker than the designed one, but the acceleration is the same. In case three we assumed that the concrete is same

as case one but increased the acceleration two times to investigate about the possibility of collapse due to the amplification of ground motion.

For decreasing the analysis time and decreasing number of elements, the pier is modeled from the top of the footing. The analysis is done for unit (cm) width of the section for all cases. We have modeled the pier as an assemblage of disks with 20cm radius and considered the effect of bars and stirrups as additional springs and dash-pots between the related concrete elements. The necessary parameters for analysis are calculated according to data from the site.

In the Pilz case, there are two important points. One is that the deck, girder and the column were constructed with each other as a uniform media. Due to this point, the vibration of the piers will be transmitted through the deck and amplify the response of the structure. The second point in construction is cut-off of the main bars in column and welding them in one section in which the concrete placement also had a time gap. This section has been a weak point during the vibration of the pier. Therefore, referring to the results of 3 cases in analysis of collapsed pier, the main possibilities for collapse are material weakness, amplification of vibration or both of them, which mainly are due to the method of construction. The result of case 3 is in more agreement with that occurred in reality comparing to the case 2. However, some other piers in the collapsed group had a collapse mechanism as the case 2.

The new pier No. 126 after reconstruction has the same height and almost the same width while its length (in transverse direction of deck) is about 6m, which is almost two times of the length of the pervious one. The section of column is almost rectangular shape and the main bars are distributed along the sides of section and mainly in a circular core in the middle of section with a diameter of about 3m. We analyzed it under the same acceleration of pervious pier in 5 cases. In the cases 4 and 5 the material properties same as the site are used under 2 to 3 times of the acceleration, respectively. In the cases 6 to 8, the tension and cohesion of concrete decreased to half amount (considering the concrete possible deterioration) and increasing acceleration from one to three times. There was no cracking in case 4, while in case 5 shear cracks appeared in the base of pier. In case 6 there was no cracks, while in case 7 crashing happened in the middle part of the column. In case 8 concrete crashing and local failure happened in the corner of the connection between column and girder. However, in all cases the pier didn't suffered total failure or collapse.

The main conclusions are:

- The developed program has the capability for fracture analysis and failure monitoring of large RC structures during the earthquake. This method can be used for simulating the existing structures for monitoring their behavior and finding their collapse mechanism during the earthquakes in future.
- The main possibilities for collapse of the old pier were material weakness, amplification of vibration or both of them, which mainly are due to the method of construction. However, good agreement between failure mode in case 3 and the one in the site shows that the amplification of the acceleration was much more possible reason for collapse.
- The new pier unlike the pervious one has shear behavior and may resists to two times acceleration without any damage. However in far future and due to concrete possible deterioration and strong motion up to three times of the maximum one during Kobe earthquake may suffer from some local failure.