INTRODUCTION

The grouted tendon was adopted to the containment building of some nuclear power plants in Korea and the assessment of effective prestress force on the grouted tendon is being issued as an important pending problem for continuous operation beyond their design life. In order to assess the effective prestress force on the grouted tendon at present, indirect assessment techniques have been applying to the test beams of grouted tendon type which were manufactured on construction time. But, test beams have a problem which doesn't be considered enough the real conditions of the grouted tendon at containment building.

Therefore, the long-term research project was started to assess directly the effective prestress force on the grouted tendon of containment building using nondestructive techniques. As a first step of the research project, the scaled model tests were carried out to investigate the variation of natural frequency according to the level of prestress force using the post-tensioned concrete beam and after this, system identification technique will be developed to identify the prestress force using the natural frequency in this study.

SCALED MODEL TEST

Post-tensioned Concrete Beam

In order to investigate the variation of natural frequency according to the level of prestress force at the grouted tendon, post-tensioned concrete beams with the grouted tendon type were manufactured and they are representative of real wall and post-tensioning system of containment building at the nuclear power plant. The total number of post-tensioned concrete beams is 6 and their length is 8.0 m and area is 0.09 (0.3×0.3 m) m². The post-tensioned concrete beam was reinforced longitudinally with 4-reinforcing bars of 16 mm in diameter and the stirrups were used for the positioning of the duct for prestressed strand with reinforcing bar of 10 mm in diameter. The 28-day compressive strength of concrete is 35.0 MPa. Load cell was installed at the one end to measure accurately the prestress force which was applied to the post-tensioned concrete beam, as shown in Fig. 1. The anchorage type for prestressed strand is VSL Type P and the diameter of prestressed strand is 15.2 mm and 3 prestressed strands were used to apply the design prestress force. The final prestress forces which were applied to each prestressed strand, are 0 kN, 146 kN, 264 kN, 356 kN, 465 kN, 523 kN and prestressed strand is located at center of the post-tensioned concrete beam. After the prestress force is applied to the prestressed strand, the cement mortar was grouted to duct.
In order to get the natural frequency of post-tensioned concrete beam according to the level of prestress force, modal tests were carried out. Among the modal tests, impact hammer test and mimo(multi input multi output) sweep test were adopted to get the natural frequency of post-tensioned concrete beam. The acceleration occurring from both tests, was measured by means of piezo-electrical sensors. In order to get the various mode shapes, 9 sensors are used as shown in Fig. 2. They were placed on top of the post-tensioned concrete beam and a sampling rate of 512 Hz was used.

Also, the loading point of impact hammer and exciter is P7 in Fig. 2. Fig. 3 shows the impact hammer test and mimo sweep test. Impact hammer test was carried out 5 times to each post-tensioned concrete beam and the measurement data were averaged. The frequency range of impact hammer is from 0 Hz to 256 Hz and the frequency resolution is 0.125 Hz. The loading magnitude of exciter is 20 N and the frequency range of exciter is from 2 Hz to 150 Hz and the frequency resolution is 0.125 Hz. In order to reduce the influence of support condition to the measurement data of the post-tensioned concrete beam, the contact area between support and post-tensioned concrete beam was minimized.
TEST RESULTS

Impact Hammer Test

Fig. 4 shows the impact signal of impact hammer and Fig. 5 shows the Frequency Response Function (FRF) according to the level of prestress force. Also, Fig. 6 shows the typical mode shapes and Table 1 indicates the natural frequency corresponding to each mode shape and prestress force.

Figure 4 - Impact signal

(a) Time domain                  (b) Frequency domain

Figure 5 - Frequency response function (Impact hammer test)

(a) 0 kN                            (b) 146 kN
(c) 264 kN                           (d) 356 kN
(e) 465 kN                           (f) 523 kN
Figure 6 - Mode shapes (Impact hammer test)

<table>
<thead>
<tr>
<th>Prestress force (kN)</th>
<th>1\textsuperscript{st} mode (Hz)</th>
<th>2\textsuperscript{nd} mode (Hz)</th>
<th>3\textsuperscript{rd} mode (Hz)</th>
<th>4\textsuperscript{th} mode (Hz)</th>
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</thead>
<tbody>
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<td>98.812</td>
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<td>523</td>
<td>8.794</td>
<td>29.850</td>
<td>99.466</td>
<td>148.334</td>
</tr>
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</table>

Table 1 - Natural frequency (Impact hammer test)

<table>
<thead>
<tr>
<th>Prestress force (kN)</th>
<th>1\textsuperscript{st} mode (Hz)</th>
<th>2\textsuperscript{nd} mode (Hz)</th>
<th>3\textsuperscript{rd} mode (Hz)</th>
<th>4\textsuperscript{th} mode (Hz)</th>
</tr>
</thead>
<tbody>
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<td>523</td>
<td>8.757</td>
<td>30.241</td>
<td>103.231</td>
<td>144.522</td>
</tr>
</tbody>
</table>

Table 2 - Natural frequency (Mimo sweep test)
Natural Frequency and Prestress Force

In order to examine the similarity of natural frequency got by impact hammer test and mimo sweep test, difference ratio of natural frequency classified by mode number according to the prestress force, was shown in Fig. 8. 1st mode shows the highest similarity with maximum difference ratio of 0.71 % and the 2nd mode shows the lowest similarity with maximum difference ratio of 10.5 %. Therefore, both tests show the good accordance to the natural frequency according to the level of prestress force and both test data are available for the system identification to predict the prestress force of grouted tendon.

In order to investigate the relationship between natural frequency and prestress force, variation ratio of natural frequency was compared by the level of prestress force as shown in Fig. 9. When variation ratio of natural frequency is calculated to each prestress force, the natural frequency by prestress force of 0 kN is standard in Fig. 9. The variation ratio of natural frequency is proportional to the level of prestress force but increasing inclination of variation ratio becomes gentle at range from 356 kN to 523 kN.

That may have a close relationship with the variation of flexural rigidity of post-tensioned concrete beam by prestress force.

As shown in Fig. 9, mimo sweep test shows better relationship between natural frequency and prestress force than impact hammer test and 1st mode is the best for the prediction of prestress force by system identification among them.

CONCLUSION

As a first step to develop the nondestructive techniques to identify the effective prestress force of the grouted tendon, the scaled model tests were carried out using the post-tensioned concrete beams with post-tensioning system of the grouted tendon type. In order to get the natural frequency of post-tensioned concrete beam according to the level of prestress force, modal tests were carried out by impact hammer test and mimo sweep test.
As a result of tests, both tests show the good accordance to the natural frequency according to the level of prestress force and both test data are available for the system identification to predict the prestress force of the grouted tendon. Also, the variation ratio of natural frequency is proportional to the level of prestress force and that may have a close relationship with the variation of flexural rigidity of post-tensioned concrete beam by prestress force.

After this, system identification process will be proceeded to predict the prestress force of the grouted tendon using the relationship between natural frequency and prestress force.

![Graph showing variation ratio of natural frequency by prestress force](image)

(a) Impact hammer test

(b) Mimo sweep test

Figure 9 - Variation ratio of natural frequency by prestress force

REFERENCES