Seismic Evaluation and Retrofit of Gas Stations: Case Study

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**ABSTRACT**

Iran is a country with high seismicity while Tehran, the capital city is home to more than 10 million people which are located on the highest seismic zone of the country. There exist 153 gas stations throughout the metropolitan which are constructed to old building codes with little or no attention to the seismic considerations. This study was conducted under a financial support by the ministry of Oil. First as built drawings were collected and studied in details. A set of new drawings were then created by detailed inspection and also some destructive tastings. This study then looked at the both mechanical and structural properties of the whole structures and their seismic behavior. This procedure was conducted for the main building, piping, tanks, shed structures as well as pumps and mechanical equipments. The loading was considered by the seismic provisions of the Iranian seismic provisions and static load analysis was carried out for the structures. This paper shows the general approach and also the detail procedure used for one such stations.

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1. INTRODUCTION

City of Tehran is located at the southern outskirts of Alborz Mountain range. This location lies in the highest seismic zone of the nation. Throughout the history this city has experienced many large magnitude earthquakes. Figure 1 shows the location of Tehran and indicates the seismic history of the region. As seen, the city with more than 10 million populations is constantly threatened by a large earthquake.

To this end, city officials are extremely concern about the well beings of the different facilities especially facilities concerning fuel. In order to address this issue, National Oil Company of Iran lunched a research program to study the 153 existing gas stations in Tehran and in case of need, to retrofit them for the possible earthquakes.

In this study, first a site investigation of each station was conducted creating a seismic hazard map for the city. A detail review of the existing drawings and creating as built drawings by opening different sections to control the original drawings then was conducted.

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After completing the as built drawings, a series of qualitative and quantitative investigations based on structural and finite element analysis was performed resulting in weak link identification for two performance criteria of life safety and immediate use levels. For buildings, life safety and for fuel tanks, immediate use was considered. Based on the analytical investigations then deem-to-comply strengthening details and drawings were constructed. The whole procedures were utilized for the main building, piping and tanks, shed structure, pumps and mechanical and electrical units in each station. This paper will provide details in regards to the procedure, findings and retrofitting techniques which were used to achieve the goals of the project [1, 2].

2. RECREATION OF AS BUILT DRAWINGS

As stated above, 153 gas stations were the subject of this study. Attempts were made to work with the original drawings. However, it was soon discovered that first of all, not all stations had drawings and second of all, those which had drawings usually major changes were done during constructions. To address this
problem, a series of points were marked on the structures, mainly the main building and the shed structures which then were opened. Then, drawings of the as built structures were recreated after inspections of the opened sections. Of course, different structures were used in different stations. A typical masonry building with steel framed shed will be present herein for the limited paper length. Pumps, fuel tanks and piping had detailed drawings and were similar in about all of the stations. Therefore, after inspections, original drawings were used for the analysis. Figure 2 shows a picture of a station used for the study. Figures 3 and 4 show the as built drawings for a complete typical station. As mentioned above, building structures were mainly constructed as masonry with Jack-Arch roofs. Some newer buildings also had structural steel framing with R/C joists as roofing system. Both types of structures were analyzed.

3. ANALYTICAL INVESTIGATIONS

3.1. Buildings In this section, a study of masonry walls and behavior of the buildings were analyzed using recommendation by FEMA 356. In plane and out of plane resistance of each wall was calculated as shown in Table 1. A program was developed to consider the in plane and out of plane resistance.

Figure 1. Location and seismicity of Tehran

Figure 2. Picture of a station under investigations

Figure 3. As built drawings of fuel tanks

Figure 4. As built drawings of typical building and shed structures of a gas station under investigation
TABLE 1. Analysis of masonry buildings, walls in both directions

<table>
<thead>
<tr>
<th>Base shear</th>
<th>V=0.33<em>A</em>I*W (ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.47</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Awi (m²)</th>
<th>Vi (ton)</th>
<th>Va=VI/Aw (kg/cm²)</th>
<th>sc (kg/cm²)</th>
<th>Vt (kg/cm²)</th>
<th>Va(Allow)=0.1 Vt + 0.15 sc (kg/cm²)</th>
<th>Va&lt;≤Va(Allow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long.</td>
<td>1</td>
<td>9.93</td>
<td>19.08</td>
<td>0.19</td>
<td>1.12</td>
<td>3</td>
</tr>
</tbody>
</table>

Direction: Long.  
Story: 1  
Areal strength of walls-Longitudinal

<table>
<thead>
<tr>
<th>Awi (m²)</th>
<th>Vi (ton)</th>
<th>Va=VI/Aw (kg/cm²)</th>
<th>sc (kg/cm²)</th>
<th>Vt (kg/cm²)</th>
<th>Va(Allow)=0.1 Vt + 0.15 sc (kg/cm²)</th>
<th>Va&lt;≤Va(Allow)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trans.</td>
<td>1</td>
<td>7.85</td>
<td>19.08</td>
<td>0.24</td>
<td>0.094</td>
<td>3</td>
</tr>
</tbody>
</table>

Direction: Trans.  
Story: 1  
Areal strength of walls-Transverse ((a) in-plane)

3.2. Shed Structure  
Shed structure was analyzed by the use of ETABS software. Structural elements were analyzed for load combinations sanctioned by the Iranian seismic provisions for capacity to demand ratios were used for evaluations based on the ratios, weak links were identified as shown in the figure.

3.3. Pumps  
Pumps were analyzed for the loads mandated by the Iranian seismic code. As seen in Figures 5 and 6, overturning and sliding of pumps were also controlled. As shown, pumps in general created no seismic threat.

3.4. Fuel Storage Tanks  
Just about all of the tanks were stored in the ground. Through piping, fuel was transferred to the pumps. Three different finite element models were considered as shown in Figure 7. As shown by the calculations, in any case, fuel tanks did not cause concern. Also, due to corrosion, a minimum thickness of 8 mm was calculated for different size of tanks as safe operation thickness. Maximum stress is shown in Table 2.

3.5. Piping  
Due to restricted piping regulations used by the Oil Company, no significant hazard was realized during inspections. All pipes were embedded on lose sand and encased by more than 2 inches of sand, around, for flexible behavior. Only problem encountered was the joint where the piping from the tanks connected to the main pips. A flexible connection was devised for better and ductile behavior as shown in Figure 8. Electrical lines and switches were all installed on the walls from the outside by flexible attachments; therefore no significant hazard was associated with them.
4. STRENGTHENING TECHNIQUES USED

Different schemes were used for strengthening different sections. For masonry buildings, main attempt was to create a structural system with providing a grid of steel sections joint with proper connections in between walls and by welding roof beams and joist to these newly framed steels. In framed buildings, addition of bracing and welding of new sections to existing ones were the main retrofitting philosophy used.

For pumps, pipes and tanks no upgrading recommendations were considered. It was suggested that if after NDT tests of tanks for possible corruptions, the thicknesses were less than the ones suggested for the safe operation by this study, it would be wise to replace the tank totally. This would be of course much economical and trying to do some alterations.

For shed structure which almost all were vulnerable, depending on type of structure, use of new and stronger connections and addition of steel plates to columns while strengthening foundations were proposed as shown in Figure 9. Figures 10 and 11 show pictures of strengthening construction used in one such station. Figure 12 shows a typical strengthening sheet for typical gas station.
Figure 10. Photo of strengthening construction in a gas station in Tehran

Figure 11. Photo of strengthening construction of a gas station in city of Tehran
5. CONCLUSIONS

In this study, 153 gas stations in city of Tehran were investigated for seismic vulnerability. In many cases, buildings and sheds were weak and needed strengthening which were designed for.

Pumps, tanks and piping needed no seismic considerations since they were designed and constructed in accordance to more restricted codes. Retrofitting has begun and it is believed upon completions, relatively safer fuel continuity will be guarantied in case of an earthquake in city of Tehran.

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7. REFERENCES


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