Experience and Testing of Supports for CAORSO Nuclear Power Plant

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Summary

The aim of the paper is to describe the results of some tests performed on CAORSO Nuclear Power Station during preoperational testing. The tests include:

a) direct static test of a piping system
b) static and dynamic tests of expansion bolts and embedded channels

The tests on the piping include cold and hot conditions analyses of the behaviour of the piping and its supports. In particular one of the supports has been removed and a hydraulic jack has been used to measure the piping stiffness. It has been found that in this case the influence of the flexible supports (hangers) is decisive (probably due to the extreme flexibility of the piping itself); some hysteretic phenomena are found and the stiffness has been found to be decreasing with the increment in the applied displacements. The large stiffness values at low displacements are assumed to be due to local phenomena (friction, contacts etc.) inside the hangers. During the hot preoperational testing the loads on the supports due to thermal movement of the piping have been monitored; some oscillations around the predicted value (again possibly due to local friction phenomena) are found, however in no case these changes jeopardize the safety coefficients for the design. Typical data are presented and discussed.

To assess the safety factors in the design of expansion bolts, some tests have been performed both in static and dynamic (fatigue) conditions. Representative results are presented and discussed. The influence of some parameters (preload, load-unload procedures etc) is shown.

Some general conclusions regarding the design of piping supports are drawn as a consequence of the tests and the lessons learnt in this way; they include: the role of ductility of the whole structure, the influence of flexible supports in the stiffness calculation of the piping, the role of local friction inside hangers and supports, the behaviour of expansion bolts and the influence of assembling procedures, the importance of proper installations and maintenance procedures.
1. **Introduction**

During the preoperational testing of CAORSO Nuclear Power Plant some test have been performed on piping and piping restraints to assess:

a) the behaviour of a representative pipeline in static conditions

b) the behaviour of some embeddings items such as expansion bolts and embedded channels in static and dynamic conditions.

The aim of the tests was to have a confirmation of the techniques and design methods used for the power station.

2. **Tests on a Representative Pipe Line**

2.1 **Cold Tests**

The tests have been performed on the FW line beyond the containment valve and the steam tunnel. A sketch of the pipeline and of the measurement points is shown in fig.1. During the test and hydraulic jack replaced a vertical rigid support in the area designated as "Forza sollevamento"; the displacements were reported as a function of the force applied by the jack; a typical displacement vs force curve is shown in fig.2.

As it is shown the curve is non linear and shows remarkable hysteretic phenomena loading-unloading cycles. The stiffness of the line is consequently a function of the displacement as shown in fig.3; as a matter of fact the stiffness decreases strongly with the displacements larger than three-four millimeters. Note that such value K≠500 Kg/mm is any how somewhat in excess of the calculated value, which is some 20% lower.

The causes of these disturbances have been identified in the large influence of elastic restraints such as hangers and snubbers on the overall stiffness of the line, which does not have any basic rigid restraint (beside the one, which has been removed to place the hydraulic jack). Friction phenomena inside the hangers are supposed to be the main cause of the differences between actual and predicted behaviour. However note that the predicted thermal displacements are generally quite larger than the "saturation phenomena", so that this irregular behaviour does not have in practice a very large importance.

Finally note that this type of behaviour has been confirmed by similar tests on a similar line; in this case the effect is less remarkable, as the influence of the hangers is lesser in this particular case.

2.2 **Hot Tests**

During the hot preoperational tests, displacements and stains on the hangers have been measured; as an example a typical force vs displacement diagram as measured on one of the hangers is shown in fig. 4. A comparison between the analytical predictions and measured values has shown reasonable agreement (even if far from perfect) as far as the displacements are concerned. The force-displacements pattern is somewhat erratic and show large discontinuities as evidentiated in fig.4 (but even worse patterns have been experienced). The reason for this behaviour should be found again in friction phenomena inside the hangers, as
already explained; however due to the nature itself of the spring hangers these irregulari-
ties do not have a particular structural meaning as they are relative only to the load variation, which represents only a small fraction of the hangers pre load.

3. **Pipe Supports Anchors Design and Testing**

An important problem which occurred in the last years in the field of the nuclear plants piping systems has been to show the adequacy of supports and seismic restraints anchors. The following ones are very common
- expansion anchor bolts (medium-heavy loads)
- embedded channels (light-medium loads)

Difficulties have been found to arise in connection with the definition of the allowable load (including consideration of dynamic loading) and with the accuracy of the installation.

Extended testing resulted in allowable loads definition and recommended installation procedures.

3.1 **Expansion Bolts Testing**

A complete picture of the situation related to expansion anchor bolts is given by Ref./1/. Expansion bolts used in CAORSO nuclear plant are of the sleeve type /2/. The base plate flexibility may affect the load distribution among the anchor bolts and reduce the safety coefficient if the assumption of rigidity is used. Most of the plates used in CAORSO nuclear plant satisfied the condition of the minimum distance between the stiffening member and the base plate edge or loads type: besides bolts location were characterized by symmetry condition which justified the assumption of base plate rigidity.

A detailed non-linear analysis was performed in a case where these conditions were not satisfied taking into account:
- plate and concrete stiffness
- bolt pretensioning
- plate-concrete non-linear interaction behaviour.

The analysis results showed that the rigid plate assumptions used in the simplified analysis were correct, the safety coefficient being 6.85 for the non-linear analysis and 6.8 for the simplified analysis.

The expansion anchor bolts design load (i.e. the maximum allowable load including SSE effects) has been determined on the basis of the bolt preload (depending upon the tightening torque) appropriately reduced by a factor varying in the range 1.4 ± 1.6 depending upon the installation accuracy. Tests have been performed in order to determine the plate concrete disjunction load (approximately equal to bolt preload): tests results and allowable design values are shown in Table I. The safety factor has been introduced to take into account installation inaccuracies, consideration of neglected loads (small amplitude fluid induced vibrations) and bolt preload residual relaxation.

The reasons why bolt preload has been considered the basic parameter are:

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a) bolt preload induces a constant stress within the concrete which will never be overcome by external applied loads. Good initial bolt tightening provides a guarantee of future anchor capacity.

b) linear behaviour of the support is guaranteed.

The safety coefficient against the anchor failure load is always greater than four except the case of 1" C40 Hardened and Tempered material bolts where a factor slightly larger than three has been accepted in view of the extensive dynamic testing performed.

While performing the initial tests a bolt preload relaxation phenomenon was discovered: a reduction of 18% after the first 4 hours in bolt pretensioning was recorded with an increase of 2% in the subsequent 21 hours. In order to allow most of the relaxation to take place, tests were therefore run 4 hours after bolt tightening.

In addition dynamic testing was undertaken to show bolts adequacy to withstand dynamic and fatigue loading: tests listed in Table II were performed followed by a static pullout test to check expansion anchor bolt ability to retain preload. Dynamic tests results showed that dynamic and fatigue loading do not affect expansion anchor bolt performance if the applied loads are lower than pretension.

As a result of the experience gained during the testing the following installation requirements were recommended:

- a) hole size and depth must be controlled. Preliminary check is required to avoid cut of concrete reinforcement
- b) bolts must be clean and lubricated
- c) bolt tightening must be carefully applied and controlled at least once after four hours.

Bolt pretensioning does not affect ultimate pullout load when concrete failure governs but, if not controlled in a multiple anchor bolts arrangement, could result in a reduction of the safety coefficient of the anchor system due to load redistribution because of bolts-plate interaction.

3.2 Dynamic Testing of Embedded Channels

Embedded channels having a pullout strength of 23 KN per 250 mm with a corresponding allowable load of 7.3 KN have been tested to show their adequacy to resist dynamic, impulsive and fatigue loads. Dynamic testing, followed by a static pullout test intended to determine the effect of such loads on the ultimate load is summarized in Table III.

Tests results lead to the following conclusions:

- a) Impulsive and high cycle loading induce loss of bond between channel body and concrete.
- b) The weak part of the system are the ends of the slots cut on the channel back where strips are inserted.
- c) Low cycle loading does not affect static performance of the embedded channel.
d) The failure static pullout load is reduced by 17% with impulsive loads and by 11% with high cycle loads: in view of these results a safety coefficient of 3.13 appears to be adequate.

<table>
<thead>
<tr>
<th>Bolt Size</th>
<th>Bolt Material</th>
<th>Torque (N x m)</th>
<th>Pullout Value (KN)</th>
<th>Disjunction Value (KN)</th>
<th>Allowable Value (KN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot;</td>
<td>C40 Hardened and Tempered</td>
<td>587</td>
<td>175</td>
<td>76</td>
<td>54</td>
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<td>1&quot;</td>
<td>Aq 50</td>
<td>392</td>
<td>&gt; 102</td>
<td>31</td>
<td>19.6</td>
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<tr>
<td>3/4&quot;</td>
<td>Aq 50</td>
<td>169</td>
<td>149</td>
<td>30</td>
<td>19.6</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>Aq 50</td>
<td>78</td>
<td>&gt; 34</td>
<td>14</td>
<td>8.8</td>
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<tr>
<td>5/8&quot;</td>
<td>Aq 50</td>
<td>98</td>
<td>88</td>
<td>18</td>
<td>10.8</td>
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**TABLE I – Expansion Anchor Bolts Allowable Values**

<table>
<thead>
<tr>
<th>Bolt Size</th>
<th>Bolt Material</th>
<th>Torque (N x m)</th>
<th>Load Range (KN)</th>
<th>No. of cycles</th>
<th>Disjunction Value (KN)</th>
<th>Intended ASME Service Level</th>
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<tbody>
<tr>
<td>1&quot;</td>
<td>C40 Hardened and Tempered</td>
<td>587</td>
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<td>85</td>
<td>A and B</td>
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<tr>
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<td>&quot;</td>
<td>587</td>
<td>0-49</td>
<td>300</td>
<td>81</td>
<td>D</td>
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<td>300</td>
<td>77</td>
<td>D</td>
</tr>
<tr>
<td>1&quot;</td>
<td>&quot;</td>
<td>587</td>
<td>0-49</td>
<td>$10^5$</td>
<td>79</td>
<td>A and B</td>
</tr>
<tr>
<td>1&quot;</td>
<td>Aq 50</td>
<td>392</td>
<td>15.7-23.5</td>
<td>$5 \times 10^6$</td>
<td>39.7</td>
<td>A</td>
</tr>
</tbody>
</table>

**TABLE II – Expansion Anchor Bolts Dynamic Testing**

<table>
<thead>
<tr>
<th>No. of cycles</th>
<th>Load Range (KN)</th>
<th>Frequency (Hz)</th>
<th>Duration (s)</th>
<th>Pullout Values (KN)</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>$5 \times 10^6$</td>
<td>5.0-7.4</td>
<td>50</td>
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<td>21.3</td>
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<tr>
<td>300</td>
<td>0-7.4</td>
<td>10</td>
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<td>24.0</td>
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<td>100</td>
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<td>-</td>
<td>0.016</td>
<td>19.2</td>
<td>Impulsive load tests</td>
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**TABLE III – Embedded Channels Dynamic Testing**
4. Conclusions

Tests on typical components of the support system were performed and summarized in this report: design values have been worked out.

Finally the authors wish to stress the importance of a ductility controlled design, i.e. a design in which the weak spot of the chain is a ductile member.

In practice differences with the prediction values are always present as a consequence of friction and other similar factors, however the practical importance of these phenomena can be safely neglected if appropriate ductility allowances are present.

References


FIG. 2 - FW PIPING STIFFNESS TEST. JACK PRESSURE VS. DISPLACEMENT

FIG. 3 - FW PIPING STIFFNESS
FIG. 4 - FW SPRING HANGER LOAD VS. DISPLACEMENT