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DESIGN OPTIMIZATION OF POT BEARINGS FOR SEISMIC LOAD EFFECTS ON BRIDGES

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ABSTRACT

Pot-bearing is a specially fabricated mechanical device, used between a bridge super-structure and its support system, that provides essential rotational degree-of-freedom to the super-structure; but it can optionally restrain the translational movement in the plane of the roadway. During seismic excitations, this optional in-plane locking mechanism transmits the inertia forces of the super-structural mass to the support structure. This paper is about the design aspects of "fixed" type post-bearings that transmit the lateral seismic inertia forces from super-structure to the support. A prototype device, suggested by a bearing manufacturer, has been analyzed by using the non-linear finite element method, for different levels of seismic lateral force demands. Based on the analysis of these results, a simple design approach has been developed that provides optimum dimensions of pot-bearing for given vertical and lateral force demands.

RESEARCH BACKGROUND

The primary design of a pot bearing is conducted based on the required vertical load capacity, V, as identified in Figure 1.

The interior diameter is calculated based on a design assumption of 30MPa bearing stress capacity, as follows:

$$\frac{\pi}{4}.d_i^{\,2}.30 = V \quad \text{where, } V \text{ in } N \text{ and } d_1 \text{ in mm.}$$

The outer diameter of a pot is considered to be 15% larger than the internal diameter, which implies the thickness of ring to be $t \approx d_i/13$.

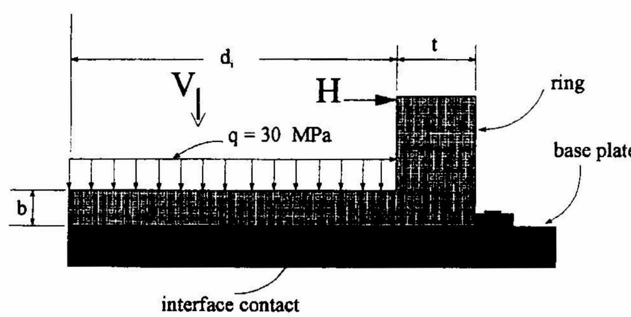

Figure 1: Cross-sectional view of a pot

The base thickness of pot is generally taken to be in the range of $d_i/13$ to $d_i/22$; the upper limit is used when the pot is directly supported by concrete structure, and the lower limit is used when a steel base plate is used underneath the pot. These structural dimensions have long been used with the assumption that the seismic lateral force does not exceed 10% of the design vertical load capacity of the pot, i.e. $H \leq 0.1V$.

However, the current design practice of bridges often specifies much higher lateral load capabilities, which may imply modifications of the existing design formulas, particularly of those related to the selection of thickness values for the pot.

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The calculation of thickness values as certain fractions of the internal pot diameter does not explicitly identify the mechanics of lateral load resistance of pots, although the design is thought to be adequate for a nominal seismic lateral load equal to 10% of the total vertical load. Consequently, a research project was pursued by SNC-Lavalin and GOODCO Ltd. with following objectives:

(i) to study the effects of increased seismic lateral forces on pot-bearings that are usually designed to carry a lateral force equal to 10% of the vertical force; and

(ii) to develop a design methodology for different levels of seismic lateral force demands.

The objective of this paper is to summarize the research work that could be useful to others interested in the design aspects of pot-bearings. Detail descriptions of the analysis results have been documented in a technical report (SNC-Lavalin 1997).

METHODOLOGY

The current design practice of pot-bearings has been determined in consultation with GOODCO Ltd., and a typical design for 500 kN vertical load has been selected for finite element analysis. This analysis result forms the reference to compare with, when further modifications are introduced into the design to resist high seismic lateral forces. The prototype has been modelled with 3-D solid finite elements. Following assumptions have been made in the numerical analyses:

- stress-strain response of steel is linear elastic;
- neoprane-pad inside the pot exerts hydrostatic pressure (Figure 1);
- seismic lateral force is distributed over a 90^0 arc on the pot-wall (Figure 2);
- the general direction of seismic lateral force is normal to the line connecting the supports at diametrically opposite positions (Figure 2); and
- the interface between bottom exterior surface of the pot and the underlying structural support is frictionless and non-cohesive.

The non-linear separation mechanism at the interface between the pot-bearing and the structural support surface has been modelled by using the Lagrangian constraint formulation as available in the ADINA software package (ADINA 1997). The response mechanism of pot-bearing system, determined during the analysis of reference model, has been applied in the second step of methodology for developing simplified design rules of pot-bearings subjected to different combinations of vertical and lateral seismic forces.

These design rules provide optimum dimensional parameters for specified load intensities. In the third step of methodology, non-linear finite element analyses have been conducted to validate and refine the proposed simplified design rules. Finally, a brief discussion about the anchorage of pot-bearing to the concrete sub-structure also has been presented.

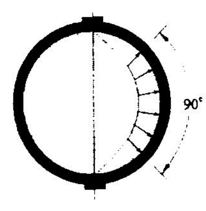

Figure 2: Distribution of seismic lateral forces on the pot

NUMERICAL SIMULATION OF POT - DESGINED BY FOLLOWING THE EXISTING PRACTICE

Finite element analysis of 500 kN capacity pot has shown that the stresses in the pots are in the acceptable range when the seismic lateral force is limited to 10% of the vertical load capacity (Figure 3(a)). This finding is consistent with the expected performance of current designs when subjected to a nominal lateral force.

In the next step, the finite element model of 500 kN capacity pot has been reanalyzed by increasing the lateral load magnitude to 25% of the vertical load. The Von Mises stress response of the model is shown in Figure 3(b). The cross sectional dimension, namely, the thickness of the ring, does not appear to be sufficient to safely resist this magnitude of applied seismic lateral force (0.25V). No separation at the interface has been considered in this particular analysis. A subsequent nonlinear simulation including the interface separation mode has shown worse stress response compared to that of the restrained base simulation. In conclusion, the structural dimensions, determined by using the current design formulas, do not appear to be sufficient to resist the seismic lateral force in excess of 0.1V.

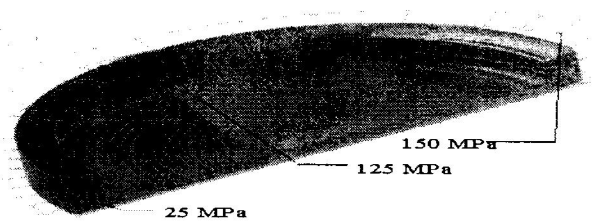

Figure 3a: Von Mises stresses in existing design of pot; nonlinear analysis with the interface separation mode.

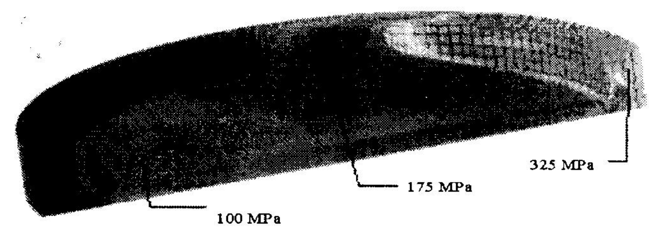

Figure 3b: Von Mises stresses in the existing design of pot; linear analysis.

MODIFICATION OF THE CURRENT DESIGN FOR HIGH INTENSITY SEISMIC LATERAL FORCES

Modifications to the current structural design are pursued in two steps: (i) by reducing the hoop stresses in the tensioned ring, and (ii) by reducing the flexural stresses at the base.

Hoop stresses in the tensioned ring

The structural response to seismic lateral force, H, and the lateral thrust of neoprene pressure, q, as shown in Figure 4, is idealized as being the uniform hoop stress in the ring:

$$\sigma_r = \frac{(H + q.c.d_i)/2}{h.t}$$

where, c, d_i, h and t are the structural dimensions as identified in Figure 4. Assuming that the average hoop stress should remain the same in two structural configurations, having dimensional values [c_0, d_0, h_0, t_0] and [c_1, d_1, h_1, t_1] and subjected to two different seismic force magnitudes H_0 and H_1, the following relationship is obtained:

$$t_1 = \frac{H_1 + q.c_1.d_1}{H_0 + q.c_0.d_0} \cdot \frac{h_0}{h_1} . t_0$$

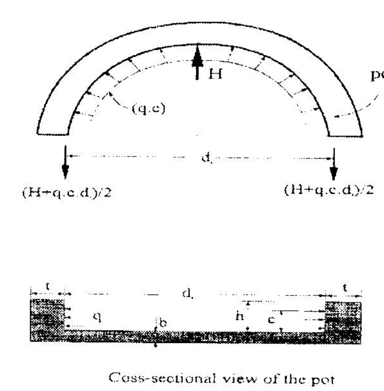

Figure 4: Tensioned ring response of the pot.

Considering that the current design configurations are adequate for the nominal seismic force, H_0=0.1V, the required structural modification for a different seismic force, H_1=αV, can be readily calculated by using the above equation, where $c_1(=c_0)$, $d_1(=d_0)$, $h_1(=h_0)$ and $t_0(=d_0/13)$ are known structural dimensions for a pot of given vertical load capacity. For example, a seismic lateral force, H_1=0.25V, on the pot having vertical load capacity of 500kN (V=5000 kN, d_0=460mm, c_0=31mm), requires an increase of the nominal ring dimension from t_0=35mm ($\approx d_0/13$) to $t_1 \approx$65mm. The design modification formula for ring thickness provides an adequate enhancement of the tensioned-ring-resistance mechanism of the pot when subjected to an increased seismic lateral force.

<u>Flexural stresses at the base of pot</u>

A two dimensional idealization of the structural response mechanism, that introduces a bending moment, M_0, at the base of pot, is shown in Figure 5. Considering the equilibrium of in-plane moments about the point A, the following relationship can be obtained between the resisting moments and the twisting moments:

$$\sum M_A = 0 \Rightarrow M_0 + \ R_0 \ \ t_0 = p_m^0 (h_0 + b_0/2) + q.c_0.(b_0 + c_0)/2$$

Here p_m^0 refers to the median value of distributed seismic lateral force on the pot, and R_0 is the contact force at the tip of interface between the pot and the base plate. The flexural stress at the base of a pot, σ_0, can be related to the internal resisting moment, M_0, through the following equation:

$$\sigma_0 = \frac{6\,M_0}{b_0^2}$$

The equilibrium between resisting moments and twisting moments is, thus, rewritten in the following form:

$$\frac{b_0^2}{6}\sigma_0 + \ R_0 \ \ t_0 = p_m^0 (h_0 + b_0/2) + q.c_0.(b_0 + c_0)/2$$

<u>Proposition (1):</u> The flexural stiffness of bottom plate of the pot is assumed to provide the primary resistance mechanism to the twisting moment introduced by the seismic lateral force. The equilibrium between applied and resisting moments leads to the following design modification formula:

$$\left(\frac{b_1}{b_0}\right)^2 = \frac{p_m^1.h_0}{p_m^0.h_0} \Rightarrow b_1 = \sqrt{\frac{p_m^1}{p_m^0}}.b_0$$

The thickness of the ring is taken to be t_1, as determined earlier to satisfy the hoop stress requirement.

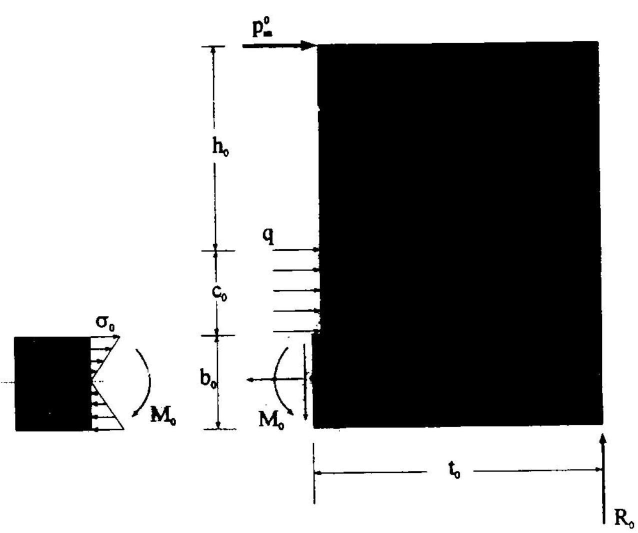

Figure 5: Two dimensional idealisation of the torsional response of pot-ring.

<u>Proposition (2):</u> The additional twisting moment, caused by an increase in the seismic lateral force, is balanced by the external resistance component only, while the internal component remains unchanged:

$$R_1(t_2 - t_0) = (p_m^1 - p_m^0)(h_0 + b_0 / 2)$$

where R_1 is the modified contact pressure. To arrive at approximately the same contact pressure value as that under nominal seismic load, the dimension t_2 can be taken as follows,

$$t_2 = \frac{(p_m^1 - p_m^0)(h_0 + b_0 / 2)}{R_0} + t_0$$

VERIFICATION OF THE NEW DESIGN MEHODOLOGY

Dimensional requirements for a pot of vertical load capacity equal to 500kN, subjected to a seismic lateral force H=0.25V, are calculated to be [b=31mm, t=65 mm] according to proposition (1), and [b=20mm, t=85mm] according to proposition(2). Nonlinear finite element analyses of the two alternative models show similar structural responses (Figures 6 and 7). Comparison of geometric dimensions shows that proposition (1) requires more material as well as more vertical space for installation, whereas proposition (2) requires larger horizontal space. When the material cost does not control pot design, either of the two solutions can be applied depending on the geometric restrictions of horizontal and vertical spaces.

As a further verification of the proposed design methodology, a nonlinear finite element analysis has been conducted on a pot with V=1000 kN and H=0.4V. The geometric dimensions have been established by following the proposition (2) of new methodology. The Von Mises stress response of this analysis model has been found to be similar to that of Figure 7. The proposed design methodology, therefore, can be used to design pots with different vertical load capacities and with seismic lateral force magnitudes as high as 40% of the assumed vertical loads.

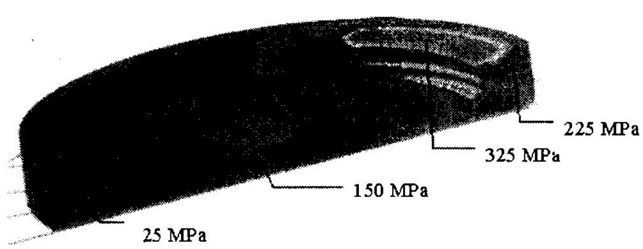

Figure 6: Von Mises stresses in pot, geometry modified by increasing the base thickness as well as the ring thickness.

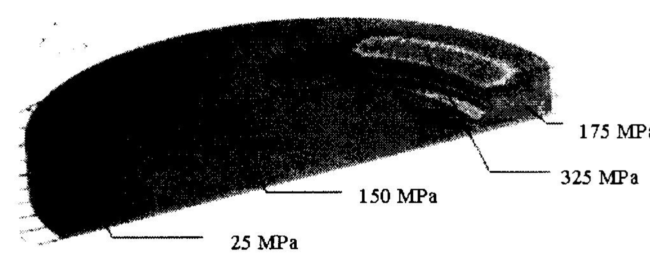

Figure 7: Von Mises stresses in pot; geometry modified by increasing the ring thickness only.

INSTALLATION OF THE POT ON A STRUCTURE

In general, two connection plates are welded to the pot at diametrically opposite positions, and these plates are welded or bolted to a base plate which is then anchored to the main structure. CSA provisions for anchor bolt and shear-stud design can be used to determine the connection configuration. A qualitative analysis of CSA provisions relevant to the anchorage of pot bearing to concrete structures has been documented in the technical report (SNC-Lavalin 1997).

CONCLUSIONS

The traditional geometric dimensions of a pot-bearing need to be modified to provide increased seismic load resistance. Two alternate propositions have been presented - (i) by increasing the thickness of the ring as well as of the base, and (ii) by keeping the base thickness constant and by increasing the ring thickness only. The structural design modification formulas have been proposed based on three key assumptions: (i) the structural resistance of pot bearings, designed by using the current simplified formulas, is adequate for a nominal seismic force equal to 10% of the total vertical load; (ii) the vertical force does not change during the application of seismic lateral force; (iii) the connections between the pot and the base plate, and the anchorage of the base plate to the concrete substructure, are adequately designed to avoid a premature structural failure. The proposed design methodology has been checked for the maximum vertical load capacity up to 1000 kN and the maximum lateral load capacity not exceeding 40% of the vertical load.

However, the manufacturers of pot-bearings will significantly benefit from a historical review of the seismic performance of bridge bearings. Further research work is also needed in: (i) the nonlinear finite element simulations of the earthquake induced vertical load reduction effects on the lateral force capacity of the pot bearings; and (ii) the experimental investigation of the complete assemblage of pot bearings to identify the critical failure mechanism. The last point is of high significance, since a well designed pot does not necessarily guarantee a sound structural behavior without properly designed connections and anchors.

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REFERENCES

ADINA, Automatic Dynamic Incremental Nonlinear Analysis, ADINA R&D Inc., Watertown, MA, USA, 1997.

SNC-Lavalin, Design Modification and Optimization of Pot Bearings Subjected to Seismic Lateral Forces, Report to GOODCO Ltd. , Project # 601063, 1997.