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Interaction Phenomena Arising Between Adjacent Buildings Numerical Investigation and Design Comments

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Abstract: In the present study one type of interaction phenomena arising between adjacent buildings was studied. The problem of load-burdening of a building due to a vertical displacement of the basement of the adjacent building through frictional load-transferring mechanisms was studied. This problem can be formulated in the form of a Quadratic Programming Problem (QP), which can be solved by any available QP algorithm. Numerical experimentation on the problem revealed the physical mechanism in this case and permitted us to discuss certain aspects on it.

Key words: Unilateral contact problem, friction, displacement

INTRODUCTION

Interaction phenomena arising between adjacent buildings very often appear in the everyday engineering praxis. Unfortunately, they sometimes appear as serious and unexpected damages, as is e.g. the case of the mutual pounding between neighboring buildings during an earthquake[1].

Even in less apparent damages, as is the case of the burdening of a building caused by a displacement at the basement of the adjacent building and the occurring load transmission from the latter to the former one, many legal as well as technical questions arise, which due to be answered in a rational way.

Although these problems are rather old and frequently appear especially in the densely built centers of the modern cities, only a little effort has been done in order to introduce the estimation of their influence in the design of the buildings. In the best of the cases, the problem is solved by abolition: building recommendations prescribe the placement of the joint of a sufficient, empirically determined width between adjacent buildings, such that no interaction occurs, or specific protection constructions against pounding are given[2].

In the present paper one of the aforementioned interaction phenomena is examined. The problem under investigation is the burdening of building caused by a vertical displacement of the adjacent building due to friction or adhesion type interactions. The rational solution of this problem is the cornerstone for alot of legal problems concerning e.g. the assignment of the responsibility and the apportion of the expenses due to damages arising in such problems.

The aforementioned problem is formulated here in the form of a unilateral contact problem, whose solution, as is known for this type of problems[3-5], can be found as the solution of a Quadratic Programming Problem. The solution procedure is outlined, while the theoretical setting, as well as the derivation of the underlying variational principles has been given by Panagiotopoulous[6]. We note here that another, more general problem is formulated[5,6], where a fixed point type iterative technique is proposed for its solution.

The main task here is the demonstration of the way in which one may find design rules and/or compose design codes by means of numerical experimentation based on the models presented. In fact, one may perform parametric investigations, as in this paper and based on the data of both the structures meeted in an area and the earthquake induced loading prescribed from the design regulations holding for the same area. These results leads to an improvement of the existing building regulations in order to take into account the interaction phenomena described. Note here that it is essential to give rules for each area, according to existing local conditions, because general rules would probably be expensive (affected from extreme values of the data), due to the high nonlinear character of the problems assumed.

On the other hand, interaction phenomena between neighboring structures are crucial for the design of the various special types of structures, cf. e.g., the influence of the relative displacements on the pipe systems bridging the interfaces in nuclear reactor installations. In that case the damages expected on the interface have to be predicted by means of some effective methods as in the herein proposed one and the results have to be used in the design procedure.

FRICTIONAL UNILATERAL CONTACT BETWEEN ADJACENT BUILDINGS DUE TO BASEMENT MOVEMENTS

Presentation of the model: In this section we deal with a problem which commonly appears, combined with the justification and the assessment of damages due to various vertical basement displacements in adjacent buildings is investigated, especially in the old centers of the cities. With reference to Fig. 2a, where two adjacent plane-frames are depicted, a vertical movement δ of the right building's basement results in a load-transfer redistribution between the two buildings. This is possible due to frictional and adhesion phenomena appearing on the adjacent surfaces of the two buildings. The result of the aforementioned stress-redistribution is a burdening of the left structure, which e.g., appears as unexpected damages due to compressive overloading in position L (Fig. 1). The calculation of the extent of this burdening through the frictionally transferred forces is the main task of the herein presented analysis. On the assumption of frictional force-transfer mechanism, as it is depicted in Fig. 1b, the following relations (Coulomb type friction assumed) are obtained:

If $-T^{ult} \le T \le T^{ult}$ then $u^r - u^l = 0$ (1)

If $|T| > T^{ult}$ then $u^r - u^l = -\lambda\, T/\,|\,T^{ult}\,|,\ \lambda > 0$ (2)

In Eq. 1-2 u^l, u^r are that left-and right-node vertical displacements, respectively and T^{ult} is the ultimate transferable force which must be estimated independently from the conditions of each case (the buildings material, the condition of the contacting surfaces, the height of their asperities, the method of the construction, the possible existence of normal interaction forces as these described in the previous section etc). Here λ is a positive real number that must be determined from the algorithm. In order to proceed into the formulation of the problem we remind that, due to the absolute value nondifferentiability, it is preferred to treat the problem in its dual from[5-8]. The minimization problem can be now written in the form:

$\prod^C(s) = \min\{0.5 * s^T F_0 s + s^T e_0 \mid Gs = P,$ (3)

And $|\,T_i| = T^{ult}_i,\ i = 1,2,\dots n\}.$ (4)

Here ${}^e o$· s·${}^F o$ are the initial strain vector, the stress vector and the natural flexibility matrix respectively, G,P are the equilibrium matrix and the loading vector respectively, and I=1,2,...,n runs over the number of adjacent nodes obeying to the force-transfer mechanism described. Problem (Eq. 3 and 4) is clearly a Quadratic Programming Problem and the Hildreth and d'Esopo algorithm[9,10] may be as well used, as in the previous case.

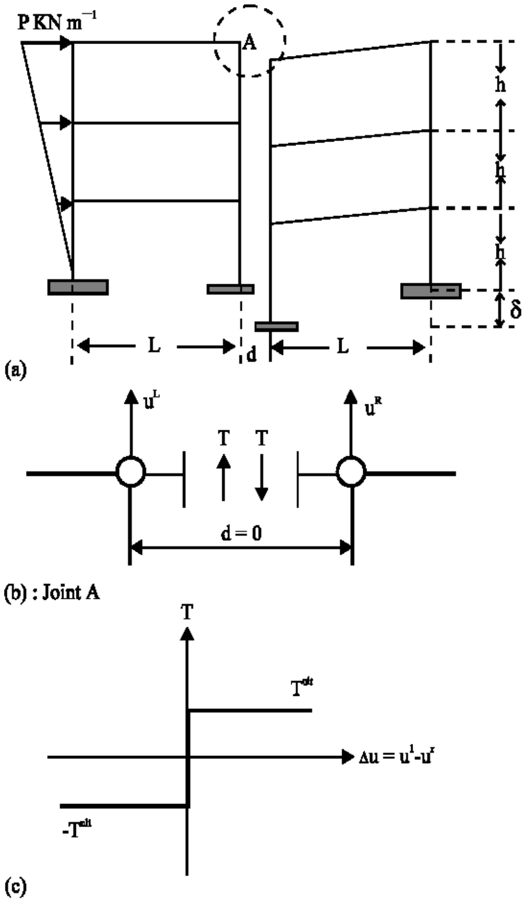

Fig. 1: The modeling of the frictional burdening problem

Concerning the interpretation of the results, the interface is divided into two parts; on the first one, no slip occurs and where the frictional loads transferred are in each point lower than the limit friction value prescribed, on the second part, the frictional transfer mechanism works within the limiting transferable friction forces and at the same time a relative slip occurs in the opposite to the friction force direction. In the latter case the algorithm gives the value of the interlayer slip as well (parameter λ in Eq. 1-2).

RESULTS AND DISCUSSION

The frictional load-transfer interaction problem for the two adjacent building shown in Fig. 2a. has been numerically treated extensively. The problem is solved for various limit load transfer capacities T^{ult} and the results are shown in Fig. 2b and c.

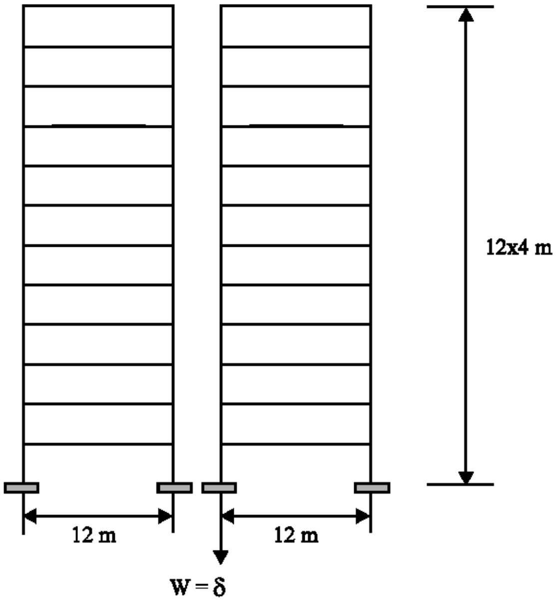

Fig. 2a: Frictional burdening between two adjacent 12-stories buildings: a) data.

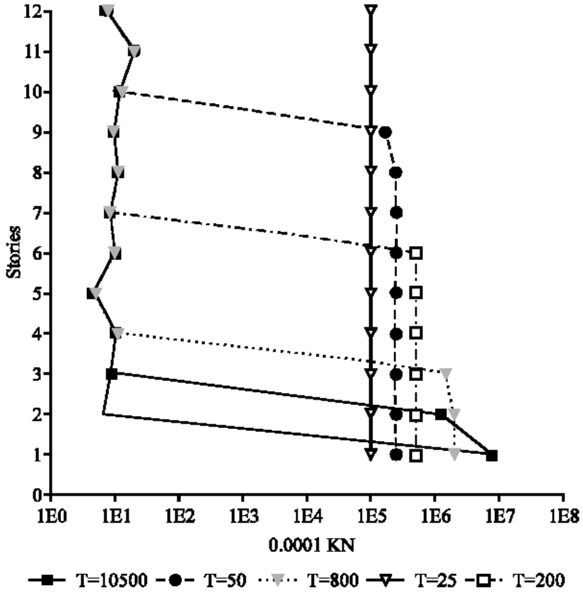

Fig. 2b: Frictional burdening between two 12-stories buildings. Schematic representation of the friction forces transferred.

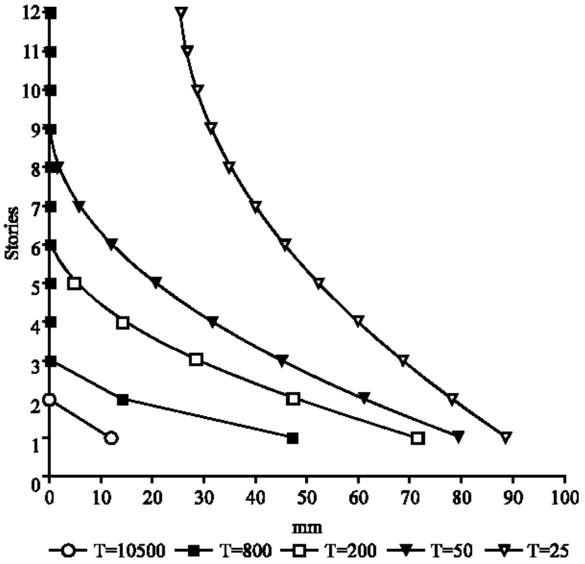

Fig. 2c: Frictional burdening between two 12-stories buildings inter-surface frictional slip, for various friction capacities.

We observe here the sharp peak in the results of the relative slip and the frictional forces near the footings of the buildings, as well as the redistribution of the frictional forces diagrams along the height of the building together with the increase of the height of the frictional slip regions (Fig. 2b and c) if the frictional transfer capacity is assumed smaller. Note also that the curves in Fig. 2b and c. denoting the maximum limiting friction load correspond to the classical analysis approach, i.e., perfect bond on the interface between the two adjacent buildings assumed, while the curves denoting the minimum limiting friction load capacity can be assumed as an approximation of the opposite structural modeling, i.e., totally independent structures.

From the results presented, one may observe that smaller limit friction load (frictional load capacity) results in an increase of the damaged area, placed in every case near the cause of the damages, i.e., near the basements of the buildings. This means at the same time that a weaker frictional connection between the buildings results in a lighter burdening of the adjacent building in the expense of greater damages on the interface due to the greater interlayer slip. The designer have to decide which is preferable for the situation at hand, i.e., either to minimize the damages due to frictional slip phenomena at the interface and to protect this way the equipment bridging the interface, or to allow this slip to appear in order to avoid greater load redistribution's and possible burdening of the neighbouring structure.

CONCLUSIONS

Concerning the first case a simple rule could be followed. As the upper part of the interface remains the last part where the frictional slip arise, it is highly recommended to place there every equipment bridging the interface between the buildings (e.g., pipes, wires etc.)

and which is susceptible to damages due to the aforesaid interfacial slip phenomena. This rule, of course, takes into account only the influence of the interfacial slip phenomena on the equipment and, for practical implementation, it has to be coupled to every other requirement arising in each specific case.

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