TEST RESULTS ON KEY JOINTS OF LARGE PANEL PREFABRICATED BUILDINGS SUBJECT TO CYCLIC REVERSED ACTIONS

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SUMMARY

The results of tests performed on typical vertical key joints subject to extreme alternate reversed shearing actions are presented in this study. The tests were performed by imposing, at each loading cycle, an incremental slip of about 1 mm. The results of the tests are described and some preliminary considerations on the calculation of the shearing strength degradation of this kind of joints are discussed.

INTRODUCTION

In large panel prefabricated structures vertical keyed joints are subject to considerable shearing forces essentially produced by horizontal actions. In the case of buildings in earthquake conditions, the shearing forces are cyclic, repeated and reversed; the hypotesis of monotonically increasing actions cannot be accepted, and the mechanical properties of the joints differ considerably from those computed for the monotonic case if, as is always assumed in earthquake conditions, the yielding of the joint is reached repeatedly and its shear slip ductility is exploited.

Expressions for the evaluation of resisting shear under monotonic conditions for keyed joints have been proposed by Tassios - Tsoukantas (Refs.1,2) and by the CEB/CIB Task Group "Design of joints in precast structures" (Ref.3). Both formulations are based on a large number of experimental tests (Refs.1, 4, 5, 6, 7, 8) and interpret the behaviour of the joint on the basis of the cracking pattern which has been observed, by introducing an "equivalent grid" mechanism.

In the case of large amplitude reversed actions however, a degradation both of the shearing resistance and stiffness is observed and should be considered in the design of this kind of joints (Refs. 9, 10, 11). A few series of tests have been performed on joints subject to cyclic actions (Refs. 1, 2, 12, 13). However, different results are obtained according to the variables which are assumed as input data. In fact, degradation of joint strength and stiffness is a function of the number of cycles but also of the maximum applied forces or, alternatively, of the value of the ductility which is, "a priori", imposed to the joint. The first approach was chosen by Pommeret et al. (Refs. 12, 13) who adopted as a basic parameter the ratio of the maximum applied force to the joint resistance under monotonic load. This approach seems to be suitable to determine the shearing resistance of joints which do not contribute to the overall ductility of the structure, that is to evaluate the fatigue performance of

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(I) Associate Professors, Department of Structural Mechanics, University of Pavia, Pavia, Italy this kind of joints (Ref. 3). To evaluate the force responce of ductility contributing joints an "imposed displacement" approach seems more suitable (Refs. 2, 3).

In this work tests are described which were performed by imposing, as far as possible, a constant incremental displacement of 1 mm. at each loading cycle. This criterion is a modification of the imposed shear slip ductility method described by CEB/CIB (Ref. 3) on which tests performed by Tassios - Tsoukantas (Ref. 2) are essentially based. However in these tests a maximum displacement of about 1 mm was imposed to the joints, while much greater displacements can be obtained. The method seems to permit a reasonable evaluation of the force response degradation of yielded joints in function of the number of cycles, and permits to explore the responce of joint, when considerable displacements take place. A tentative expression to evaluate the degradation of shearing strength is also given. The chosen slip of 1 mm corresponds, for this kind of joints, to the yield slip ductility under monotonic load as verified in (Ref. 6).

EXPERIMENTAL TESTS PERFORMED

Experiments were performed on three types of joints:

Type A: keyed joint with three castellated keys, three horizontal stirrups and one vertical bar. The inclination α of keys is 45 degrees. This type of joint is a standard type used in large panel constructions and was studied extensively by many authors, expecially for monotonic load histories. See fig.1.

Type B: a typical keyed joint which is composed of three vertical elements obtained with poured in place concrete. These elements are connected by three horizontal keys. Reinforcement is composed of three horizontal stirrups and two vertical bars. See fig.2.

Type C: it is the same as type b, with thermal insulation added.

For each type of joint two prototypes were manifactured. Each prototype was obtained by coupling two panels. Geometrical dimensions are reported on figg.1 to 3. Material properties are given on table 1.

TYPE	TEST	f_{cm} N/mm^2 *	f_{sy}	f_{SR}	STIRRUP DIAMETER
A	A1 A2	38.6	439	601	8.4
B	B1 B2	22.5	456	613	8.8
C	C1 C2	38.6	439	601	8.4
* cube mean resistance of joint concrete					

Table 1 - Material properties

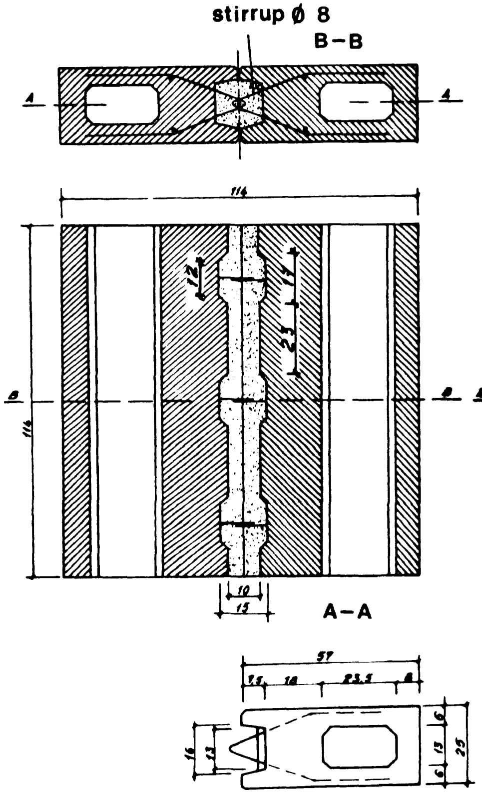

Figure 1 - Type A joint

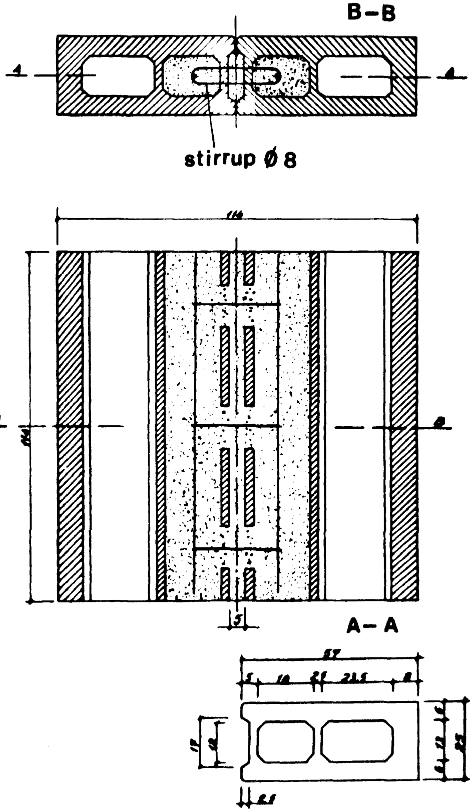

Figure 2 - Type B joint

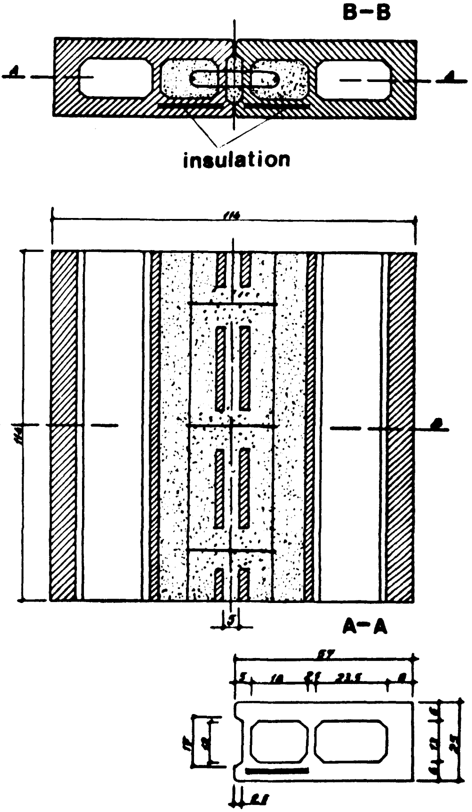

Figure 3 - Type C joint

Elements were tested with alternate reversed loads using the equipment represented on Fig.4. Load increment velocity was very low (static tests). Pure shear was obtained, keeping the external force exactly on the joint axis, using the arrangement represented on Fig. 5.

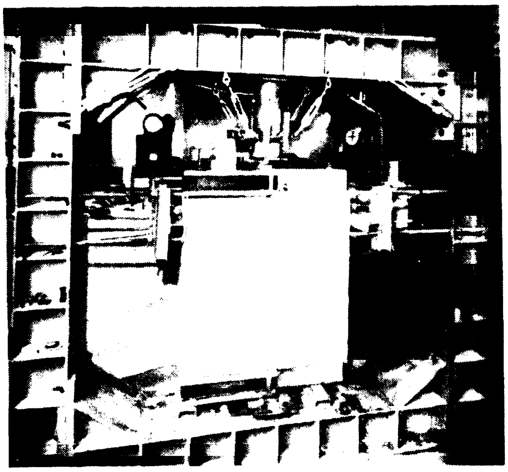

Figure 4 - Equipment used in test

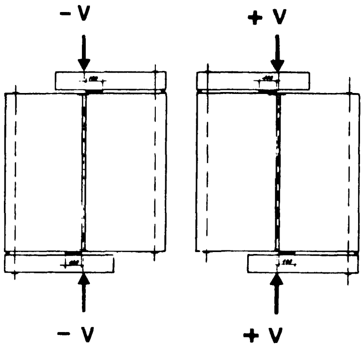

Figure 5 - Test arrangement

During the tests the most relevant displacement component (vertical slip) was measured. This was performed using a couple of transducers placed on both sides along the joint. These measurements were plotted automatically using an analogic X - Y recorder, on the X axis. Loading measurements were obtained through a load cell and plotted on Y axis. It was thus possible to record the complete load history and the joint response. The joint slip was used as a control parameter in the experiments As a conseguence, each half-cycle was performed with the same maximum displacement as the corresponding half-cycle of opposite sign. The results are represented on Figs. 6, 7, 8.

INTERPRETATION OF TESTS

By observing the results of the tests, it is interesting to note the followings:

- In the first cycle a very high stiffness is often produced by the considerable bond between poured in and precast concrete, whose value cannot be "a priori" stated.
- The maximum shearing strengt is normally obtained for joint slips of over 2 mm.
- At each loading cycle, the adopted procedure does not guarantee the reaching of the maximum potential resistance at the cycle.

The degradation of the shear resistance determined at each cycle with the testing procedure which was previously described, follows, expecially for the joints of type A, a fairly regular pattern which can be represented

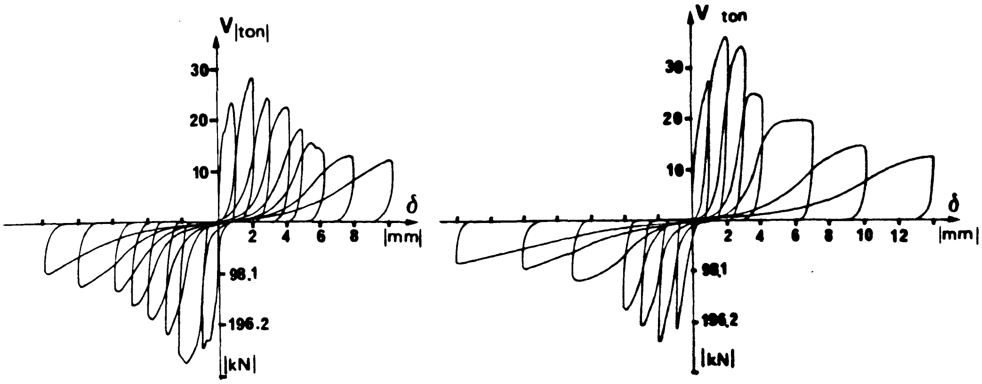

Fig. 6- Shear-slip diagrams (Type A tests)

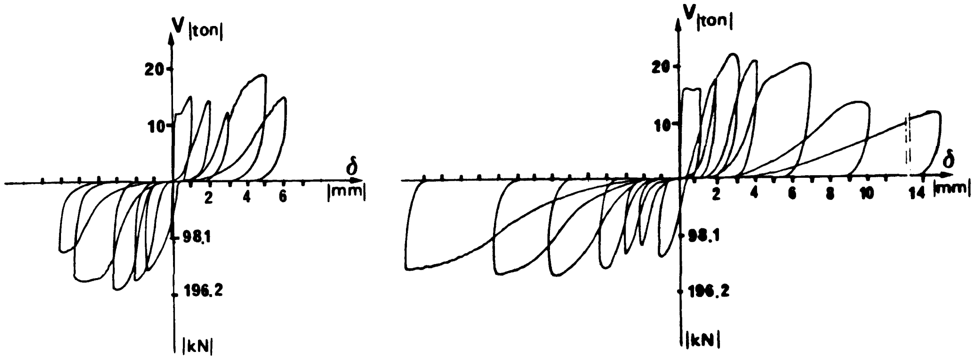

Fig.7- Shear-slip diagrams(Type B tests)

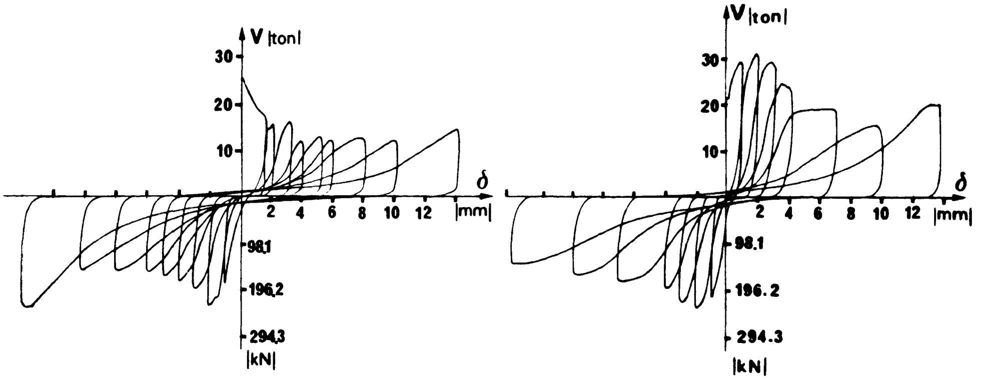

Fig.8- Shear-slip diagrams(Type C tests)

by an analitical expression. With all the reservations which are imposed by the limited number of tests and by the adopted procedure, the following expression was tentatively adopted:

$$R_{jd}^{VE} = R_{jd}^{V} \qquad \text{for } n \leq 2$$

$$R_{jd}^{VE} = R_{jd}^{V} \left[0.4 + 0.00937 \, (10 - n)^2\right] \qquad \text{for } 2 < n \leq 10$$

$$R_{jd}^{VE} = 0.4 \, R_{jd}^{V} \qquad \text{for } n > 10$$

being :

R_{jd}^{VE} shear resistance under cyclic actions

R_{jd}^{V} shear resistance under monotonic loads computed according to the analytical expression proposed by Tassios (Refs.1, 2) or CIB (Ref.3)

n number of loading cycles.

On Fig.9 this expression is plotted both for design and mean values of material strengths. On the same figure the obtained experimental values are reported for each loading cycle and for type A joint which shows a more regular behaviour.

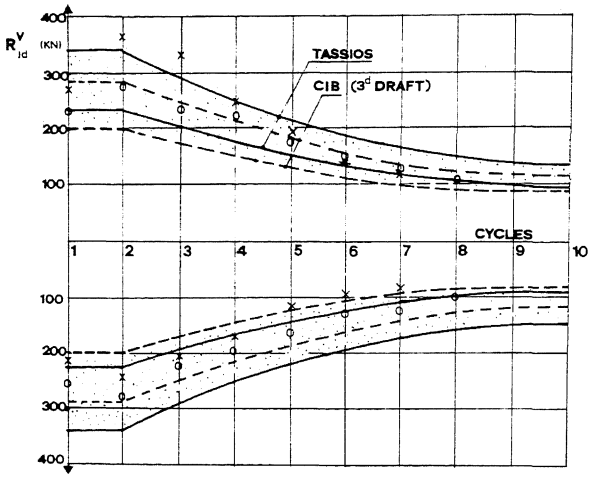

Figure 9 - Shear resistance versus N. of cycles. (Type A Joint)

As can be seen from the diagram, experimental values fit fairly well in the band delimited by the upper curve (mean value of material resistances) and the lower one (design values).

PRELIMINARY CONCLUSIONS

Although the results concerning tests on vertical keyed shear joints subject to extreme alternate reversed actions are determined by the criteria adopted in the application of loads, which need to be more clearly defined adn furtherly discussed, it may be concluded preliminarly that the degraded values of force response of keyed vertical joints can be with sufficient accuracy computed using a suitable analytical expression in function of the number of extreme loading cycles to which the structure can be subject during a given earthquake. This number can be derived by the shape of the accelerogram of the earthquake under consideration.

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