EXPERIMENTAL DETERMINATION OF NEOPRENE-CONCRETE FRICTION COEFFICIENT FOR SEISMIC ASSESSMENT OF EXISTING PRECAST STRUCTURES

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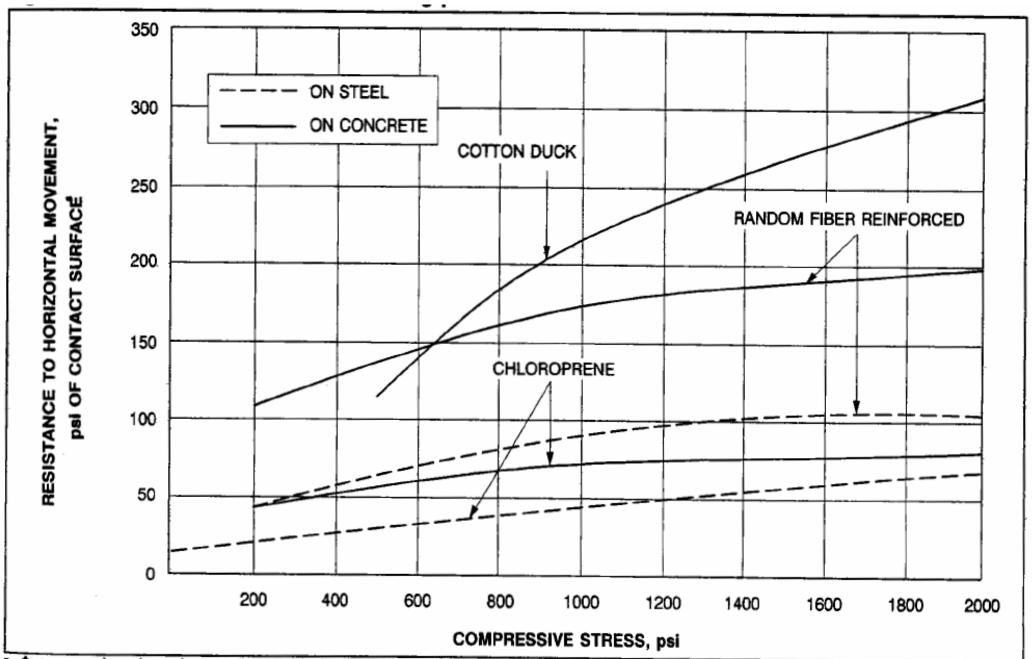
ABSTRACT :

In Italy many precast industrial buildings built between 1950s and 1970s are characterised by beam – column connections based on concrete-neoprene friction strength.
Numerical studies recently performed by the authors confirm that, in order to determine the seismic vulnerability of such structures, a reliable value of the neoprene-concrete friction coefficient must be known. Technical bibliography provides many and different values of this coefficient; consequently, in order to define a reliable value, a specific experimental campaign is carried out. Three typologies of experimental tests are performed: tests on neoprene hardness, tilting tests and pulling tests, where the specimen is also axially loaded. In this paper set - up, methodology and results of such tests are accurately described. The tilting tests provide a value of the mean friction coefficient equal to about 0.5. The tests with axial strain underline a dependence of the slip strength by axial load and, in particular, a decrement of the friction coefficient as the axial load increases.

KEYWORDS: Neoprene-concrete friction coefficient, experimental tests, beam-column connections, precast concrete existing buildings, seismic vulnerability

1. INTRODUCTION

The presented study is in the frame of a project concerning the seismic vulnerability of precast industrial buildings built in Italy between the 1950s and the 1970s (Fabbrocino et al. 2004, Magliulo et al. 2008).
The part of the project already carried out may be divided in two phases. The first one is characterised by the definition of the typologies and structural characteristics of the considered buildings, with particular reference to connections, by a large bibliography research, interviewing technicians who worked in the field during the reference period and studying actually executed projects. Consequently, some reference buildings representative of the most spread typologies during the reference period are selected. The second one, instead, is characterized by numerical analysis (modal elastic analysis and non linear static and dynamic ones). They showed that, even under seismic forces characterising a medium intensity Italian seismic zone, precast existing buildings, whose beam-column connections are based on concrete-neoprene friction strength, can collapse due to the loss of support. Consequently, in order to determine the seismic vulnerability of such structures, it is necessary to know the value of the neoprene – concrete friction coefficient.
Few references related to the determination of such coefficient can be found in bibliography and its value, ranging from 0.6 to 0.9 (Di Pasquale et al., 1991; Esposito and Mauro, 2003; Raymond, 1996, Southern Illinois University 2004), concerns applications different from structural ones (Di Pasquale et al. 1991, Esposito and Mauro. 2003, Raymond 1996, Southern Illinois University 2004); furthermore, it is not specified the level of axial force corresponding to the provided value. The PCI design handbook (PCI, 1999) is the exception. The variation of the neoprene-concrete friction strength, provided for unity of neoprene support surface, is plotted varying the axial stress (solid line, chloroprene, in Fig. 1) in the interval 1.4 N/mm^2 - 14 N/mm^2; it can be observed that in such interval the friction strength for unity of surface varies from about 0.3 N/mm^2 to about 5.6 N/mm^2, with a friction coefficient that varies, therefore, between 0.22 and 0.04. These low values confirm the possibility of structural collapse of industrial precast buildings whose beams are simply connected to columns and whose horizontal strength depends on friction strength (Magliulo et al., 2008).



a. Average values based on tests at 70% shear and slippage strain.

Figure 1 Variation of the friction strength varying axial strain (PCI,1999)

2. TILTING TEST

The friction (static) coefficient μ_s is determined in accordance with definition, i.e. as tangent of the friction angle θ_a, that is the angle corresponding to the attainment of the maximum value of the friction strength; for larger angles the specimen slips on the inclined plane (Fig. 2):

$$\mu_s = tg\theta_a = T_{friction} / N \tag{2.1}$$

The test set up (Fig. 2) is represented by a rotating frame where it is constrained a concrete plate, characterised by a seasoning longer than 7 days and by a smooth surface, which is typical of the element part in contact with the formwork. The neoprene specimen is glued to a concrete brick, which provides the necessary load to perform the test and guarantees an uniform contact between neoprene and concrete surfaces; the neoprene is then placed on the concrete plate.
The tests are performed on two specimens of different dimensions: the first one is 20cm x 9cm x 1cm, while the second one is 25cm x 20cm x 1cm; consequently, the contact surfaces are 180cmq and 500 cmq. The first specimen is loaded by a concrete block whose dimensions are 24cm x 12cm x 5 cm and whose weight is equal to 36 N; the second one is loaded by a concrete block whose dimensions are 25cm x 30cm x 5cm and whose weight is equal to 93.8 N. The corresponding contact stress are equal to σ = 0.0020 N/mmq and σ = 0.0018 N/mmq respectively, which are negligible.
Four LVDT transducers of inductive type HBM (Fig. 2) are used in order to measure the displacements. Two of them are attached to the concrete brick (A and B in Fig. 2), in order to measure the displacements along the inclined plane; the other two (E and F in Fig. 2), vertically positioned, are connected to the rotating frame in order to measure its rotations.

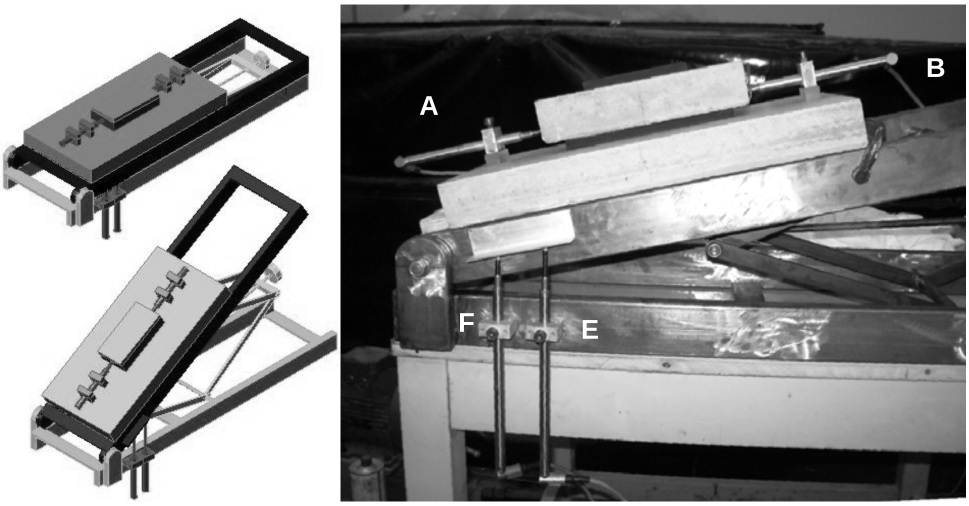


Figure 2 Test set up on inclined plane

The test consists in slowly rotating the frame with a manual system (end-less screw). The neoprene specimen does not slip till the angle of the inclined plane is lower than the friction one ($\theta < \theta_a$); when the two transducers set on the inclined plane measure a displacement, it means that the friction force is overpassed. The test is stopped and the angle measured by the vertical transducers corresponds to the friction angle. The transducers are connected to a system for data collecting type Spide 8 and elaborated by the software Catman version 3.0.
The results concerning the 21 tests performed on the two described specimens are reported in Table 1: the 21 friction coefficients (μ), the average of such coefficients (μ_{mean}) and their standard deviation (s.d.$_\mu$) for each specimen and for all the obtained results. The total average is equal to $\mu_{mean} = 0{,}492$, while the standard deviation is sufficiently low, i.e. lower than the 10% of the μ_{mean}, showing that the mean result is reliable and

the tests enough accurate.

Table 1 Results of friction tests on inclined plane

Neoprene specimen	Test n.	μ	μ_{mean}	$s.d._{\mu}$
20 x 9	1	0.528	0.526	0.053
	2	0.437		
	3	0.493		
	4	0.516		
	5	0.629		
	6	0.566		
	7	0.541		
	8	0.471		
	9	0.584		
	10	0.501		
	11	0.520		
25 x 20	12	0.444	0.454	0.043
	13	0.433		
	14	0.513		
	15	0.496		
	16	0.459		
	17	0.393		
	18	0.409		
	19	0.482		
	20	0.410		
	21	0.504		
			0.492	0.048

3. PULLING TEST

3.1. Initial test set up

Results of tilting tests cannot take into account the influence of axial load levels on the rubber bearing; this is the reason why specific pull-out tests have been carried out. The aim of the tests is to obtain the neoprene-concrete friction coefficient that can be attained under serviceability conditions of an existing connection.

The first set up is composed by two lateral concrete blocks whose dimensions are 60.5x60.5x25 cm and a central steel plate; at each side of such plate a neoprene specimen, whose dimensions are 30x15x1, is glued by an universal cold-vulcanizing sticker (TOP TIP REMA SC-2000). The neoprene-concrete contact surfaces are subjected to an axial load, assigned by an hydraulic horizontal jack, located in a "cradle", which acts on two metallic plates, one of them uniformly distributes the load on the concrete block and the other one, on the other side of the jack, restrains it. This plate is restrained by bolts to three steel bars, as well as another steel plate which is placed in correspondence of the external surface of the concrete block on the other side with respect to the jack; such two steel plates close the system.

The two neoprene specimens, by the steel plate and a steel pipe, are connected to a vertical jack. This provides the shear force parallel to the neoprene surface, making contrast on a double T profile, which is supported by two strengthened HE180A profiles, which run on the top surface of each concrete block; a Teflon sheet is placed between the profile and the concrete block, in order to avoid undesirable frictions. Vertical bars, bolted to the two HE180A profiles, ensure the needed restraint to the floor; in fact, the tensile action applied on the rubber determines on the blocks an overturning moment which is controlled by the vertical bar clamping action.

The displacements are measured by inductive transducers and potentiometers.

In particular, neoprene displacements are detected by six potentiometers, two for each neoprene specimens

connected by a steel screw, one for each side, and two on the steel plate which supports it; consequently, both the deformations of the rubber and the absolute displacement of the steel plate when the friction is overpassed, can be detected. The potentiometers are fixed to an external support, which is not influenced by the set up deformations.
The transducers, LVDT of inductive type HBM, are connected to the two concrete blocks in order to detect the relative displacement among them, and, then, the axial deformation of the packet. In particular, four transducers are used, two for each block, one at the bottom side of the block and the other one at the top side, in order to also evaluate possible rotations of the blocks. Even such instruments are connected to a system for data collecting type Spide 8 and elaborated by the software Catman version 3.0.

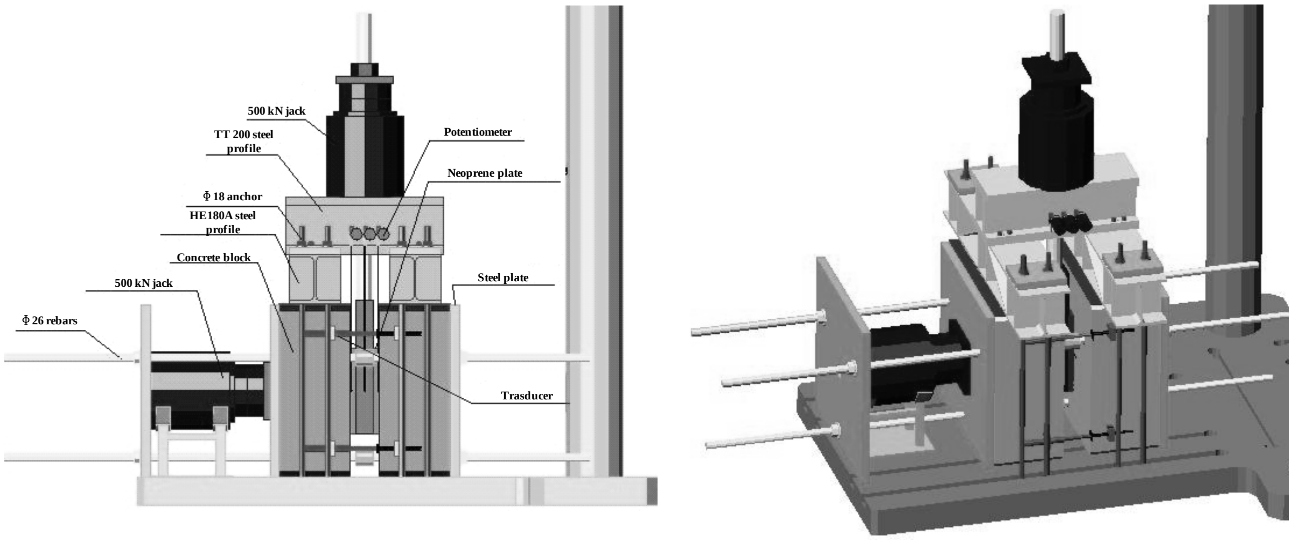


Figure 3 Initial pull test set up

3.2. Final set up

Two tests are performed by the presented set up, characterised by compressive forces equal to 80 kN and 120 kN respectively. A relative displacement between the neoprene specimens and the steel plate is observed, showing the glue failure; this happens at a transversal force equal to 20 kN, which correspond to a transversal stress equal to 0.44 N/mmq. Consequently, the initial set up is modified.
The steel slab is replaced by a concrete block. A threaded bushing, type 30 MA with a capacity of 40 kN, is adopted in order to pull the concrete block.
The central concrete block is cast so that its surface presents the same characteristics of the column top surface, while the internal surface of the external blocks is cast in order to reproduce the same surface of the bottom part of the beam, which is smooth due to the formwork; in this way, real conditions of the beam to column connection are reproduced.
Furthermore, the neoprene specimen is not glued to the central concrete block, but it is simply placed between the two concrete blocks by a line , so that the surfaces of concrete and neoprene are parallel and centred with respect to the axial load (Fig. 4).

Figure 4 Final pull test set up

This set up is resulted better than the previous one due to the following reasons: 1. the beam to column connection is more faithfully reproduced due to the fact that the neoprene is not glued neither to the beam nor to the column; 2. the neoprene conditions are more easily monitored and it is more easily replaceable in case of damage.
The elements that transmit vertical force by the jack to the neoprene specimens, i.e. the central concrete block and vertical bar, have a total weight equal to 1 kN; consequently, such weight is subtracted to the applied shear force.
The displacements are monitored by two LVDT, which measure the displacements of the central block with respect to the lateral ones and, consequently, the neoprene displacements with respect to these ones; indeed, the specimens do not slide with respect to the central concrete block, due to its more rough surface (Fig. 4).

3.3. Test results

Twenty tests are carried out, four for each level of axial force: 80 kN, 120 kN, 160 kN, 200 kN and 240 kN. The last one is a limit value, due to the normal stress limitation on neoprene specimens, equal to 5 N/mmq in accordance with the (CNR 10018, 1999).
The results of the 20 performed tests are reported in Table 2: the 20 friction coefficients (μ), their average for each level of axial load (μ_{mean}), the plan neoprene dimensions (b, h) and the neoprene normal (σ) and transversal (τ) stress.
For each axial load level, the force parallel to the neoprene/concrete surface (shear force) is increased monotonously increasing the displacement with a speed equal to 0.02 mm/s; the test is interrupted when the neoprene begins to slide on the concrete and the displacement increases at a constant shear force value. The half of the shear force, from which the weight of the central block has been subtracted, divided by the axial load, represents the friction coefficient.
The values of the shear force and of the displacements are collected by the program Catman version 3.0: the program is set up in order to plot the increment of shear force related to the displacements measured with the two LVDT transducers.

Table 3.1 Results of pulling tests

Test name	N	T (x 2)	μ_i	μ_{mean}	b	h	σ	τ
	[kN]	[kN]			mm	mm	[N/mmq]	[N/mmq]
80 (2)	80	21.38	0.1336	0.131	150	300	1.778	0.238
80 (3)	80	19.00	0.1188		150	300	1.778	0.211
80 (4)	80	21.14	0.1321		150	300	1.778	0.235
80 (5)	80	22.42	0.1401		150	300	1.778	0.249
120 (2)	120	29.76	0.1240	0.120	150	300	2.667	0.331
120 (3)	120	27.10	0.1129		150	300	2.667	0.301
120 (4)	120	30.50	0.1271		150	300	2.667	0.339
120 (5)	120	28.10	0.1171		150	300	2.667	0.312
160 (1)	160	38.52	0.1204	0.115	150	300	3.556	0.428
160 (2)	160	35.60	0.1113		150	300	3.556	0.396
160 (3)	160	37.30	0.1166		150	300	3.556	0.414
160 (5)	160	35.80	0.1119		150	300	3.556	0.398
200 (1)	200	45.26	0.1132	0.114	150	300	4.444	0.503
200 (2)	200	48.00	0.1200		150	300	4.444	0.533
200 (3)	200	45.80	0.1145		150	300	4.444	0.509
200 (4)	200	43.60	0.1090		150	300	4.444	0.484
240 (1)	240	43.70	0.0910	0.095	150	300	5.333	0.486
240 (2)	240	46.30	0.0965		150	300	5.333	0.514
240 (3)	240	44.50	0.0927		150	300	5.333	0.494
240 (4)	240	48.80	0.1017		150	300	5.333	0.542

3.4. Comparison with the data provided by PCI Handbook

The comparison between the results of the tests and the friction values provided by PCI Handbook is shown in Figure 5. The neoprene normal stress (σ) is reported on the horizontal axis, while the transversal one (τ) on vertical axis. It results that for low values of normal stress, the friction coefficients provided by the tests are lower than those found in bibliography; the contrary happens for normal stress larger than 3 N/mm^2. However, the compared results are close.

In Figure 5 the linear regression curve of the tests mean results is also plotted; the value of the regression coefficient, equal to R^2=0.948, is large. It also confirms the trend of the PCI Handbook curve, i.e. the light decrement of the friction coefficient as the normal stress increases.

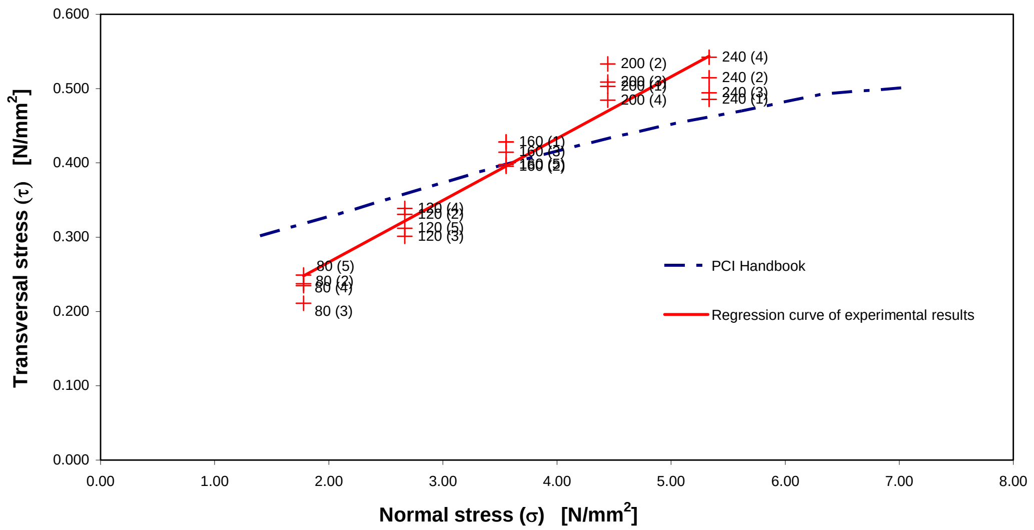


Figure 5 Comparison between the tests results and friction coefficients curve provided by the PCI Handbook

4. CONCLUSIONS

The tilting tests provide a mean value of the friction coefficient equal to about 0.5, with a sufficiently low coefficient of variation, i.e. lower than 10%.
The friction coefficient determined by experimental tests with normal stress varying between σ = 1.7 and σ = 5.3 N/mmq varies in the range 0.09-0.13. Furthermore, it lightly decreases as the normal stress increases, confirming the data found in bibliography.
The low values of the friction coefficient provided by the tests and the results of numerical analyses reported in other papers underline the low resistance to the seismic actions of the precast industrial buildings built in Italy before 1970s; they, even for earthquakes of medium intensity, can collapse for loss of support.

ACKNOWLEDGEMENTS

This research has been partially funded by Italian Department of Civil Protection in the frame of the national project ReLUIS – theme 2.
The authors thank Eng. Luigi Manto and Eng. Antonio Gloria of Department of Engineering of the Materials and of the Production at University of Naples Federico II for collaboration on hardness tests and Eng. Mauro Redaelli for collaboration on friction tests.

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