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Punching of Concrete Shells under Ship Collision

Poinçonnement de coques en béton lors des collisions de navires

Durchstanzen von Betonschalen bei Schiffskollisionen

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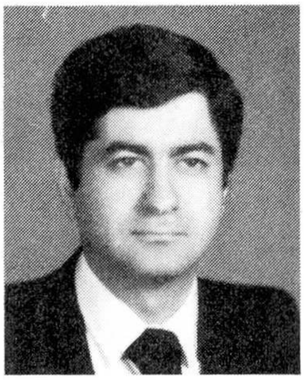

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SUMMARY

In connection with the problems of ship collision with supporting systems of concrete gravity structures, many concrete cylinder specimens were subjected to impact load with a speed of about 1.5 m/s. The local effects of the tests are compared with the effects of concentrated load on concrete cylinders. In the tests the size and shape of the load application area, the rate of reinforcements and the level of prestressing were varied in order to investigate the effect of this upon the failure load. A design method for punching shear of concrete cylinder is presented.

RÉSUMÉ

Pour étudier le comportement des piliers des structures offshore en béton sous l'effet de la collision de bateaux, plusieurs coques cylindriques en béton ont été soumises à l'impact d'un projectile avec une vitesse de 1,5 m/s. L'effet local d'impact a été comparé avec l'effet de la charge concentrée sur des cylindres en béton. Les dimensions et la forme de la zone d'application de la charge ont été modifiées ainsi que le pourcentage d'armature, afin de voir leur influence sur la charge de rupture. Une méthode de calcul de la résistance au poinçonnement des coques cylindriques est présentée.

ZUSAMMENFASSUNG

Um das Verhalten der Betonpfeiler von Offshore-Bauten unter dem Zusammenstoß von Schiffen zu studieren, sind mehrere zylindrische Betonschalen an einem Geschoßeinschlag von 1,5 m/sek Geschwindigkeit unterworfen. Die lokale Stoßwirkung wurde mit einer Einzelkraftswirkung auf einer Betonschale verglichen. Die Größe und die Form der Stoßzone wurden verändert, ebenfalls der Bewährungsprozent, um den Einfluß auf der Bruchlast zu bestimmen. Eine Durchstanzwiderstandrechnungsmethode wurde für zylindrische Schalen vorgestellt.

1. INTRODUCTION

To study the local effect of ship collision on offshore gravity structures, C.E.B.T.P.* has undertaken a research program since 1979. At first the aim was to determine the nature of impact and see the difference between its local effect and punching shear failure.

An attempt is made to find the influence of reinforcement and longitudinal prestressing. In this field many tests have been performed on cylindrical concrete shells. These tests allowed us to propose a design method for punching shear. We wish to mention that this research program was financialy supported by ARBEM (French Association for concrete at Sea) and French Ministry of Transport.

2. DESCRIPTION OF TESTS

2.1 Models and test equipments

The tower of structure receiving the collision was modelized by a cylindrical concrete shell showing an approximate ratio of 1/10 between thickness and diameter. We consider only the accidental collision (see definition - Ref [1]) of the supply boat with a collision speed about 1.5 m/s. In this case the duration of impact is longer than the shaft's own period and the problem of dynamic amplification, due to structure vibration, is not encountered. Therefore in our test we have not studied the effect of vibration. To reduce the flexural effects we maintened our concrete cylinder in a special steel device (fig. 1). Mortar was injected between the steel cylinder and concrete shell.

A 30 x 60 cm opening is left at the top of the device to allow load application.

2.2 Orientation tests

The aim of these tests was to compare the local effect of impact of a rigid body at a low speed (about 1.5 m/s) with punching shear failure (load applied by a hydraulic jack).

In both cases, the load was applied by a circular, 120 mm diameter, steel puncheon.

The impact tests were carried out by fall of a steel ram. The ram was made of 300 mm diameter steel discs, assembled around a steel rod (see fig. 2). The mass may be modified according to the needs of the test. The ram falls from heights of 115 mm (v = 1.5 m/s). The deformations and local deflections in several points of the cylinder and also the impact force were recorded.

It emerged from the tests that at failure, the impact loads are nearly the same as punching shear loads.

In both cases, at failure, a concrete plug is punched out in the direction of the load, the rest of the cylinder remaining intact. The upper part of the plug keeps the shape of the puncheon. The dimensions and shape of failure surface are very similar (see fig. 3).

After this phase we continued our tests with static concentrated load. Many tests were performed with different shape (circular and elliptic) and different size of puncheon.

In some cases to achieve a good contact between concrete and puncheon we used a concave puncheon with a interposed rubber sheet. In these particular cases we observed an increase of failure load about 18 %.

* C.E.B.T.P. : Centre Expérimental de Recherches et d'Etudes du Bâtiment et des Travaux Publics.

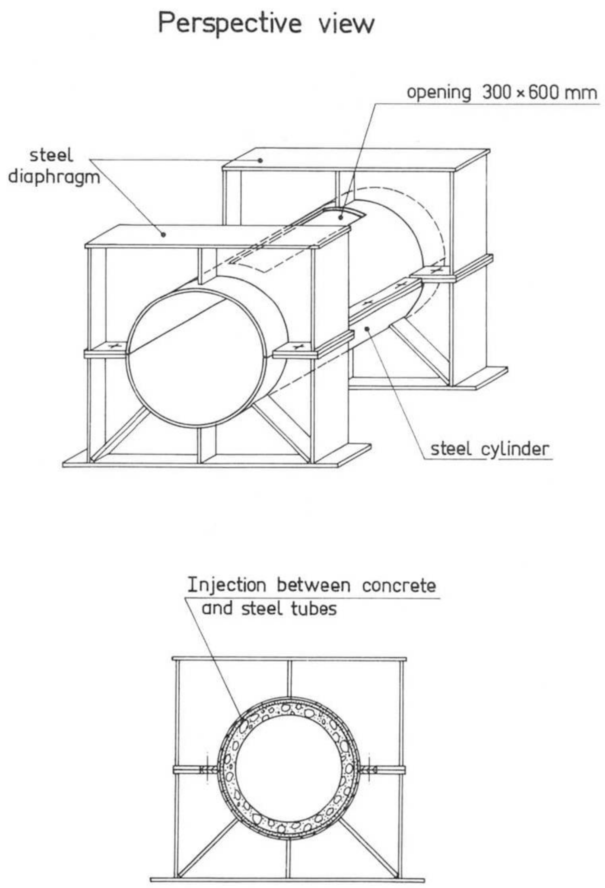

Fig. 1 Testing equipment

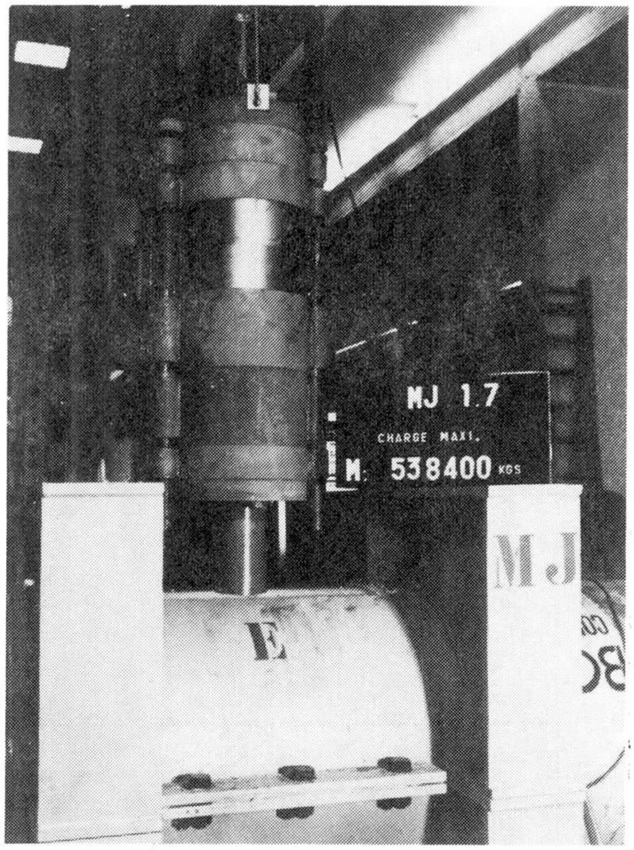

Fig. 2 Steel ram

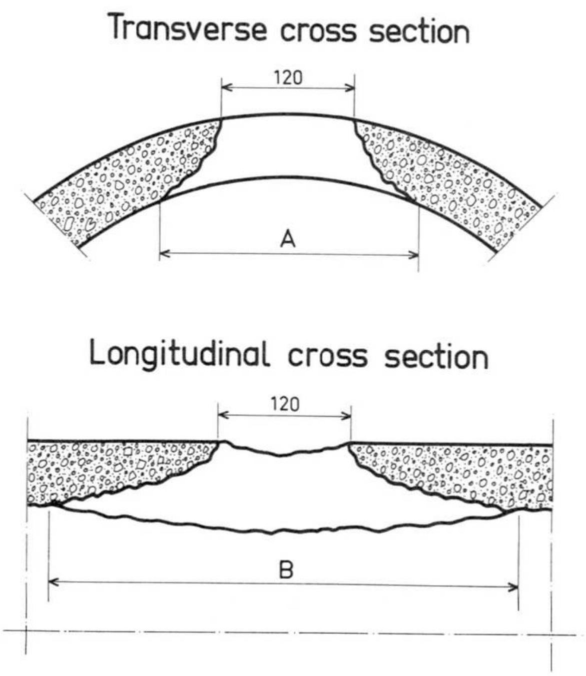

Fig. 3 Failure surface

	Essai	Amm	Bmm
Static Test	MJ1.1	270	440
	MJ2.1	290	400
Dynamic Test	MJ1.7	260	430
	MJ1.9	230	420
	MJ1.13	260	460
	MJ2.5	290	440

Reference of test	Form of Steel nose	Failure load (KN)	Ratio $\frac{\text{Test failure}}{\text{Theoretical failure}}$	Ratio $\frac{\text{Experimental B}}{\text{Theoretical B}}$	Ratio $\frac{\text{Experimental A}}{\text{Theoretical A}}$
1.1	circular 120 mm	233,7	0,98	0,99	1,14
2.1	circular 120 mm	254,8	0,95	0,90	1,22
3.2	circular 100 mm	225,4	0,99	1,08	1,07
3.3	elliptic 150 x 100 mm	254,8	0,98	0,93	1,11
3.4	circular 140 mm	401,8	1,1	1,04	1,22
3.5	circular 50 mm	170,5	1,23	1,1	1,26
4.1	elliptic 150 x 100 mm	235,2	0,91	1,00	1,11
4.2	elliptic 150 x 100 mm with neoprene	331,1	1,09	0,97	1,16
4.3	elliptic 150 x 100 mm curved with neoprene	313,6	1,03	1,00	1,16
5.1	"	224,4	0,94	0,91	0,99
5.2	"	234,6	0,99	0,98	1,18
5.3	"	234,6	0,96	1,00	1,04
5.4	"	244,8	0,99	0,95	1,18
5.5	"	265,2	1,06	0,98	1,13
5.6	"	244,8	0,96	0,95	1,18
5.7	"	153,0	0,87	0,80	1,08
5.8	"	145,9	0,83	0,87	1,13
5.9	"	153,0	0,81	0,87	1,04
5.10	"	163,2	0,85	0,78	1,18

TABLE 1

The observation of failure surface confirmed the previous results. All these tests were carried out on the standard ducts produced by BONNA (716 mm external diameter and 58 mm thickness). The rate of reinforcement was not very high.

2.3 Tests with prestressed concrete

In order to investigate, the influence of concrete strength, reinforcements and prestressing, we used five specially made concrete cylinders. Two types of reinforcement (Ø 6 mm spaced 5 cm in two directions and Ø 6 mm spaced 8 cm in two directions) are considered. The reinforcement was in the mid thickness of cylinder. The ultimate strength of concrete varied between 28 to 58 MPa. The prestressing force varied from 0 to 500 KN.

The effect of reinforcement and longitudinal prestressing upon the failure load turns to be slight, on the other hand a higher rate of reinforcement leads to higher ductility of failure.

3. DESIGN METHOD

Our tests have shown that local effect of ship collision with offshore plateforms is similar to punching shear failure. To estimate the punching shear strength of cylindrical concrete shells an analytical solution is developped. The method is a generalization of the method presented by BRAESTRUP [2] for punching shear in concrete slabs.

A plastic limit analysis based upon the failure mechanism is used to calculate the punching load, we equate the external work produced by the punching force with the internal work dissipated in the failure surface. To satisfy the requirements of limit analysis, we assumed that concrete is a rigid, perfectly plastic material with the modified coulomb failure criterion as yield condition and the deformations governed by the associated flow rule (normality condition).

The load found by equating the rate of external and internal work is an upper bound solution for the punching load. By minizing this load, we approach the real punching load. For more details see réf [3].

This solution does not give only the punching load but it also determines the failure surface and takes in account the exact shape of puncheon. A comparison between calculated and experimental failure load and failure surface is givenin table 1. To compare the experimental and calculated failure surface, we have chosen the length of the two perpendicular axes at the base of plug, as comparison criterion. See fig. 3.

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