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Test on Mojo barriers for determining strength, overturning resistance and sliding behaviour

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SUMMARY

Loading tests have been performed by TNO-Building and Construction Research in order to investigate the strength and the modes of failure of Mojo-barriers. Since the barriers are applied as stand alone barriers without fixing to the ground, the tests were aimed at the following modes of failure:

- strength of a single unit
- overturning of a single unit
- sliding on a smooth concrete floor, on carpet and on rubber mats

Strength of single barrier unit
The strength of a single barrier (ultimate limit state) with regard to a horizontal line load at the upper rail amounts to 6.6 kN/m.

Overturning of single barrier unit
The overturning resistance of a single barrier with regard to horizontal force at a height of 1.1 m above ground surface amounts to 5.3 kN/m.

Sliding resistance of single barrier unit
The sliding resistance on a smooth concrete floor with finishing amounts to 2.9 kN (or 2.6 kN/m), on carpet 4.1 kN (or 3.7 kN/m) and on a rubber mat 4.3 kN (or 3.9 kN/m).

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1 INTRODUCTION

On request of Production Design Utrecht Holland BV, The Netherlands, a series of loading tests have been performed on barrier units. The barriers are used as temporary fences at the front of the stage at pop-concerts.

The loading test were aimed at verifying the structural strength of the barries itself as well as to assess the modes of failure (sliding, overturning and structural failure) the barriers might develop as a result of various crowd densities.

This report contains a description of the test method and the results of the tests. The tests were originally executed in the laboratory of TNO Building & Construction Research April 22nd-26th, 1993. This report has been issued on request of Production Design Utrecht Holland BV covering those barriers that are currently marketed.

2 DESCRIPTION AND INTENDED USE OF THE BARRIERS

Photographs 1, 2 and 3 show the barrier units. The barriers are demountable.

One single barrier unit consists of a base frame welded of square hollow section units. The base frame contains a foot plate. Attached to the base frame is an A-frame. The A-frame is connected to the base frame by means of bolts. The side of the A-frame that directs toward the crowd is vertical. The top rail of the barrier is at a height of 1.2 m above ground level.

Single barrier units can be coupled together by means of a pin-joint connection. This results in a straigth barrier row. Annex 1 gives some additional information on the possibility of building barriers of concave or convex shape using the barriers units in conjunction with special accesories.

The barriers are used as crowd control barriers during pop concerts. According to an earlier investigation by Halcrow Consulting Engineers (see Annex 2), during pop concerts the maximum number of people standing on single barrier will be between 8 and 10 in case of any significant horizontal loading on the barrier. These numbers were observed during a Bon Jovi concert at the Ahoy Theatre in Rotterdam in 1989.

Irwin [1] reports static live load between 7.3 and 8.7 kN/m^2 in front of the stage, measured during 'The Who' concert in the Playhouse Theatre, Edinburgh in 1981.

3 TEST METHOD

3.1 General procedure

A horizontal load is applied at the top rail of the barrier, that is at 1.2 m above ground level. For this purpose, a stiff beam was used together with a flexible rubber compound between the beam and the top rail, in order to distribute the load uniformly along the top rail. The length of the top rail and accordingly of the applied line-load is 1.09 m.

On the foot plate a gravity weight is applied between 3 kN and 10 kN, in steps of 1 kN using blocks of steel. The gravity weight was distributed uniformly over the plate. The steel blocks were weighed before the test.

The load is being measured using a load cell between the hydraulic jack and the barrier. The displacement of the top rail of the barrier and the displacement of the base frame of the barrier are measured using Linear Voltage Displacement Transducers (LVDT).

Table 1: Test Equipment

Description	**make/type**
hydraulic jack	Lukas/400 kN
load cell	TNO/20 kN
displacement transducer	Sangamo/50 mm
displacement transducer	Celesco/PT101

3.2 Test A

The barrier is placed on a smooth concrete floor. The horizontal load is applied together with a gravity load of 3 kN on the base plate of the barrier. The horizontal load is continuously increased until sliding occurs. Then the gravity load is increased by 1 kN and the test is repeated until a gravity load of 10 kN is reached or structural failure occurs

3.3 Test B

The barrier is placed on an underlay, spread out over the smooth concrete surface. The underlay consists of a rubber mat, thickness 2 mm, which has been fixed to the concrete surface. The test procedure described in Section 3.2 has been followed. The test has been repeated using an underlay consisting of carpet.

3.4 Test C

The barrier is placed on a smooth concrete floor. The horizontal load is applied together with a gravity load of 3 kN on the base plate. Sliding of the barrier is prohibited by a steel bar, placed in fornt of the base frame. The test procedure is to load the barrier with a weight of 3 kN an to apply an increasing horizontal load until structural failure or overturning occurs. In case overturning occurs the horizontal load is released, the weight is increased by 1 kN and the test is repeated. Overturning is measured by means of a displacement transducer measuring the vertical uplift of the base frame of the barrier.

4 TEST RESULTS

Table 4.1: Results of test A for barrier 90-281 (sliding on smooth concrete)

gravity load (kN)	total horizontal load (kN)	horizontal load (kN/m)
3	1.6	1.47
4	1.9	1.74
5	2.1	1.92
6	2.4	2.20
7	2.7	2.48
8	3.1	2.84
9	3.4	3.12
10	3.7	3.39

Table 4.2: Results of test A for barrier 92-158 (sliding on smooth concrete)

gravity load (kN)	total horizontal load (kN)	horizontal load (kN/m)
3	1.7	1.56
4	2.0	1.83
5	2.5	2.29
6	3.0	2.75
7	3.4	3.12
8	3.8	3.48
9	4.2	3.85
10	4.3	3.94

Table 4.3: Results of test B for barrier 92-158 (sliding on rubber mat)

gravity load (kN)	total horizontal load (kN)	horizontal load (kN/m)
3	2.0	1.83
4	2.9	2.66
5	3.4	3.12
6	3.7	2.75
7	4.2	3.39
8	4.9	4.50
9	5.4	4.95
10	6.0	5.50

Table 4.4: Results of test B for barrier 90-281 (sliding on carpet)

gravity load (kN)	total horizontal load (kN)	horizontal load (kN/m)
3	2.5	2.29
4	3.0	2.75
5	3.6	3.30
6	4.0	3.67
7	4.4	4.04
8	5.0	4.58
9	5.4	4.95
10	6.1	5.59

Table 4.5: Results of test C for barrier 92-134

gravity load (kN)	total horizontal load (kN)	horizontal load (kN/m)
3	2.7	2.47
4	3.3	3.03
5	4.0	3.67
6	4.8	4.40
7	5.7	5.22
8	6.5	5.96
9	7.2[2]	6.60
10	-	-

2) The test was stopped at the initiation of bending of the base frame at a load of 7.2 kN. Photograph 6 shows the deformed shape of the barrier at this stage of the test.

5 DISCUSSION OF RESULTS

5.1 Sliding resistance

The mean sliding resistance on smooth concrete with finishing can be approximated by the following formula, based on regression from the measured results given in tables 4.1 and 4.2:

$F_{hor} = 0.57 + 0.35\ G$

where

F_{hor} is the total horizontal load on the barrier to initiate overtuning, in kN

G is the vertical static load on the barrier unit.

The sliding resistance of a barrier placed on a rubber mat:

$F_{hor} = 1.01 + 0.50\ G$

The sliding resistance of a barrier placed on carpet:

$F_{hor} = 0.54 + 0.54\ G$

5.2 Overturning resistance

For barrier unit 92-134 the overturning horizontal force can be approximated by the following relation, based on regression from the test results:

$F_{hor} = 0.26 + 0.77\ G$

For comparison to the UK pop code, it should be noted that this test has been applied with a load acting on 1.2 m above the ground surface, whereas the UK pop code specifies 1.1 m. For this specific height, the overturning resistance will increase by a factor of 1.2/1.1, leading to:

$Fhor = 0.28 + 0.84\ G$

5.3 Expected vertical static load on the barriers and assessment of resistance

The barriers are used as crowd control barriers during pop concerts. According to an earlier investigation by Halcrow Consulting Engineers (see Annex 2), during pop concerts the maximum number of people standing on single barrier will be approximately 10 in case of any significant horizontal loading on the barrier. These numbers were observed during a Bon Jovi concert at the Ahoy

Theatre in Rotterdam in 1989. Irwin [1] reports static live load between 7.3 and 8.7 kN/m^2 in front of the stage, measured during 'The Who' concert in the Playhouse Theatre, Edinburgh in 1981.

High horizontal forces on the barrier can occur only in combination with very high crowd densities in front of the barrier. Following the observations made by Halcrow (refer to Annex 2) and taking a crowd density of 10 persons barriers unit, the dead load on the barrier can be calculated from the mean weight per person.

The following means and standard deviations for the weight of adults apply:

	mean	standard deviation
male	78 kg	9.3 kg
female	66 kg	9.5 kg

Some additional weight should be added for clothing and shoes. A reasonable estimate for this is 2 kg. During pop concerts, the average age of the people will probably be under 20 and will be distributed in a narrow band around this age. Therefore, it seems more realistic to adopt the mean weight of males and females between 17 and 19 years of age.

age	male	female
15.5-16.5	66.1 kg	55.1 kg
16.5-17.5	69.2	55.9
17.5-18.5	73.2	55.9

Taking 75 kg including clothing for young males and 58 kg including clothing for young females and assuming an equal distribution of males and females in the crowd in front of the barrier, a mean weight pro person of 66.5 kg can be taken.

The gravity load on the barriers at high crowd densities (10 persons per barrier unit) can therefore be estimated to be at least 10*66.5*9.81 = 6.5 kN per barrier unit. Since the floor area of the foot plate of the barrier is 0.76 * 1.09 m^2 = 0.83 m^2, this is equivalent to a equally distributed load of 7.8 kN/m^2. This agrees with the measurements reported by Irwin showing static live loads in the range between 7.3 and 8.7 kN/m^2.

Using the value of 6.5 kN per barrier unit, the overturning resistance for a load acting on a hight of 1.1 m above the ground surface amounts to 5.7 kN per barrier unit or 5.3 kN/m.

For the sliding resistance on a smooth concrete floor it then follows 2.9 kN (or 2.6 kN/m), on carpet 4.1 kN (or 3.7 kN/m) and on a rubber mat 4.3 kN (or 3.9 kN/m).

5.4 Ultimate resistance in bending

The ultimate resistance in bending of a single barrier unit amounts to 7.2 kN per barrier or 6.6 kN/m.

6. CONCLUSIONS

Loading tests have been performed by TNO-Building and Construction Research in order to investigate the strength and the modes of failure of Mojo-barriers. The tests were aimed at the following modes of failure:

- strength of a single unit
- overturning of a single unit
- sliding on a smooth concrete floor, on carpet and on rubber mats

The tests have been performed on 3 barriers manufactured in 1990 and 1992 (having the identification numbers 90-281, 92-134 and 92-158).

Strength of single barrier units
From the tests it is concluded that the strength of the barriers (ultimate limit state) is reached at a horizontal line load at the upper rail of a single barrier of 6.6 kN/m. The failure mode of the barrier is bending of the lower frame.

Overturning of single barrier units
The horizontal force at a height of 1.1 m above ground surface required to initiate overturning is 5.3 kN/m.

Sliding of single barrier units
The sliding resistance of a single barrier unit on a smooth concrete floor with finishing amounts to 2.9 kN (or 2.6 kN/m), on carpet 4.1 kN (or 3.7 kN/m) and on a rubber mat 4.3 kN (or 3.9 kN/m).