#1282

COMPARISON OF THE STRENGTH REQUIREMENTS FOR CONCRETE PAVING BLOCKS IN 16 COUNTRIES

An analysis based on the inquiry into specifications and standards for concrete paving blocks

S.G. van der Kreeft, Laboratory 'TWELLO', Twello, The Netherlands

When the Programme Committee CBP decided in 1981 to set up an inquiry into concrete paving blocks, many countries was asked to answer a comprehensive questionnaire. The questionnaire was returned by 16 countries.

It was expected that the inquiry would show a main line, but when processing the inquiry (together with Houben and Leewis) this soon appeared not to be the case at all.

The Conference paper deals in particular with the sampling, the dimensions, the dimensional tolerances and the strength of the concrete paving blocks.
It is usual to draw conclusions. Summarized: it is a chaos!
The strength and the dimensional tolerances are indeed investigated as essential facts, but the ways of testing are incomparable. Nor the number of blocks in a sample, nor the method of testing nor the requirements are comparable.
In illustration of the sampling: for each of the 16 countries the number of concrete blocks, for which 1 unit of the sample is representative, was determined; it appeared that this number varies from 300 up to 80,000 (see the figure on page 6 of the Conference Proceedings)! How to interpret this figure?
For example the point close to the sign 'Is': at least 70% of the correspondents of the inquiry takes at least 1 block from a lot which is smaller than 8,000 blocks. And 50% of the correspondents takes at least 1 block from a lot of 4,400 blocks. Assuming that one day production of one machine is about 40,000 blocks and supposing furthermore that in general 40 blocks cover 1 m^2, the conclusion is that for this crucial 50% point (about the median of all correspondents) 1 sample unit represents 110 m^2 block paving. This means that from one day production of one machine 9 blocks are sampled. It seems a rather good idea to sample on an average every hour 1 block from one machine.

After writing the Conference paper a further investigation of the inquiry was carried out. This investigation was focussed on the strength requirements in order to obtain comparable results.

Three different strength tests are used: compressive strength, splitting strength and flexural strength.
Apart from special measures in these tests, such as the application of packing sheets or the polishing of the contact faces of the specimens, it was possible to derive from the literature (Narrow and Ullberg; Goldbeck; Graf; and others) for concrete paving blocks:

$$\text{flexural strength} = 1.10 \times \text{splitting strength} + 1.88 \quad (N/mm^2)$$

According to Hummel, Graf and Gehler, for concrete paving blocks holds:

$$\text{compressive strength (cube 150 mm)} = 3.09 \times (\text{flexural strength})^{1.5} \quad (N/mm^2)$$

The ratio between the compressive strength and the flexural strength is 7.5 on an average; however, this ratio tends to increase with increasing strength (which is conformable to experience).
The ratio of the flexural strength and the splitting strength is 1.7 on an average.
The afore-mentioned equations and figures concern the flexural strength and the splitting strength of the blocks on one hand and the compressive strength of a cube with sides 150 mm (manufactured from the same concrete and with the same degree of compaction as the block) on the other hand.
Now the main terms are interrelated. However, when reading the inquiry attentive, it appears that in particular the compressive strength is tested in totally different ways: on the full-size block or on cubes or cylinders from the blocks, while in two countries the test is done with steel plates, area 2500 mm^2, on the full-size block!
There are a number of graphs available to deduce, for a certain type of specimen, the effect of the dimensions relative to a standard dimension. Some of these graphs are shown in the figures 1 and 2. This is a well-considered choice after having studied many, and often different, relationships.

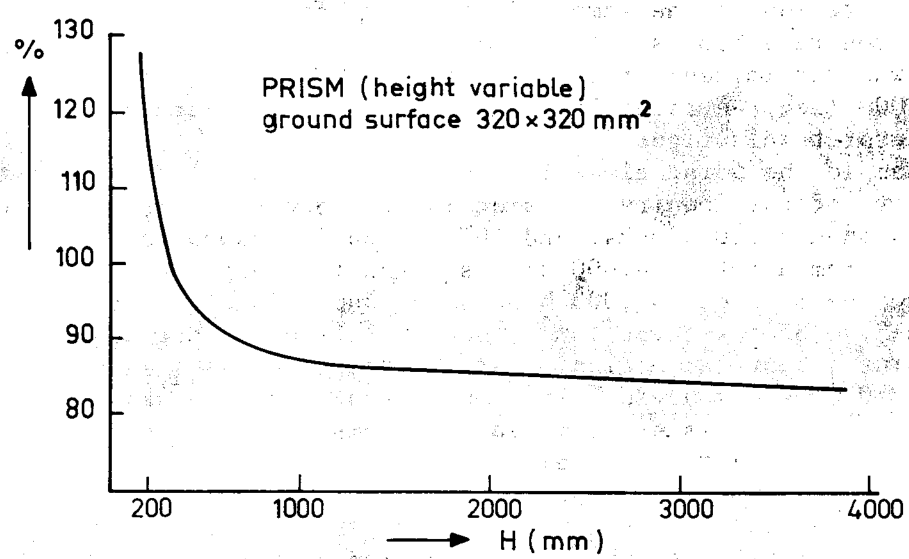

Figure 1. Relative strength of prisms with variable dimensions.

In 1966 Neville assumed that for the same concrete the strength of the specimen is dependent on three variables: the volume V, the greatest lateral dimension D and the ratio of H and D (H = height).
Because it is common practice in The Netherlands, let's take a cube with sides 150 mm as a standard for the determination of the compressive strength of concrete. It appears after some calculation that for every specimen a shape facor P can be determined according to:

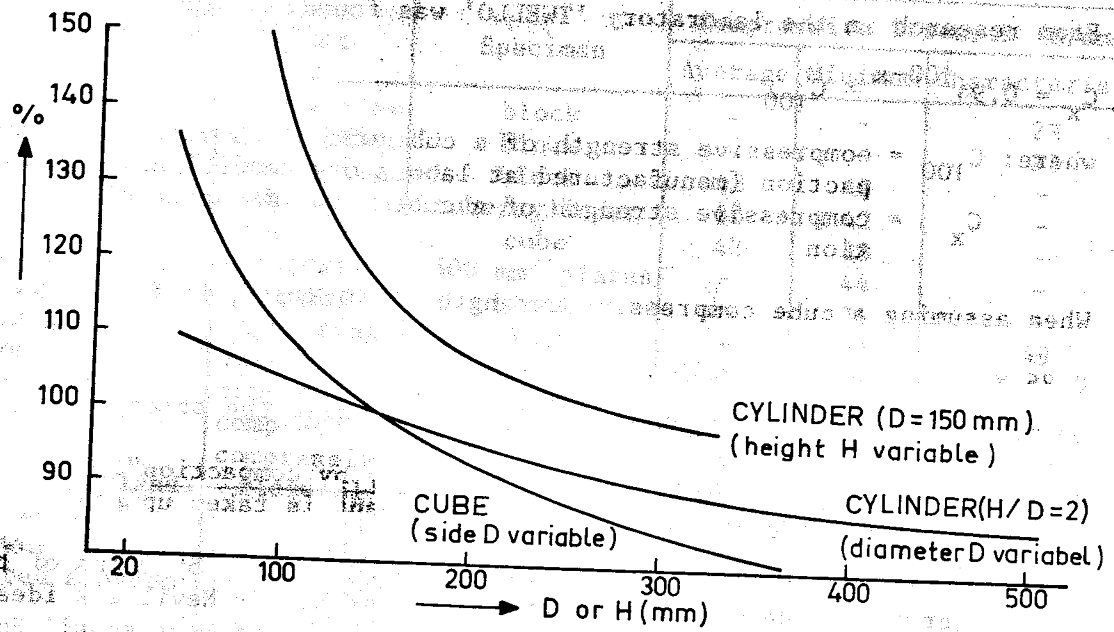

Figure 2. Relative strength of cylinders and cubes with variable dimensions.

$$P = \frac{150\ H\ D}{V + 150\ H^2}$$

So the shape factor of the standard cube is:

$$P = \frac{150 \times 150 \times 150}{150^3 + 150 \times 150^2} = 0.5$$

And the shape factor of a cylinder with diameter 100 mm and height 100 mm is:

$$P = \frac{150 \times 100 \times 100}{\frac{1}{4} \times \Pi \times 100^2 \times 100 + 150 \times 100^2} = 0.656$$

In the Dutch concrete prescriptions it is stated that the compressive strength of a cylinder with diameter 100 mm and height 100 mm, taken from the concrete work, is equal to the compressive strength of a cube with sides 150 mm, manufactured in the laboratory.
Later it will be shown that the compressive strength of the cylinder has to be 1/0.86 times greater.
The difference in compaction between concrete from the work and concrete manufactured in the laboratory causes that, in case of the same composition of the concrete, an equal compressive strength is found for the cylinder and the cube. The degree of compaction is defined as the ratio (percent) of the dry density of the practice concrete and the dry density of the concrete, compacted in the laboratory.

From research in the laboratory 'TWELLO' was found:

$$C_x = 0.94^{100-x} \times C_{100}$$

where: C_{100} = compressive strength of a cube with 100% degree of compaction (manufactured at laboratory conditions)
C_x = compressive strength of a cube with x% degree of compaction

When assuming a cube compressive strength of 40 N/mm^2, it follows:

$$0.86 \times 40 = 0.94^{100-x} \times 40$$

So the degree of compaction x is only 97.5%, while the strength is 14% smaller!
Therefore the device should be: "only quality by compaction".
After this side-step the thread of the argument is taken up again.

After having rewritten all the afore-mentioned figures by means of the shape factor P it appeared, with great admiration for Neville's ideas, that the lines for cubes, cylinders and prisms were almost equal! Small deviations are supposed to be caused by the applied graphs for the effect of specimen dimensions as these relationships often differ.
The lines for cubes, cylinders and prisms not only are equal, but they are a straight line with the simple formula:

$$M = 1.467 - 0.927 P$$

For the standard cube with sides 150 mm thus is found:

$$M = 1.467 - 0.927 \times 0.5 = 1.00$$

which can be expected for the multiplication factor M.

Taking into account the specific test conditions in every country, in table 1 their strength requirements have been transformed into the compressive strength of a cube with sides 150 mm.

For a real comparison of all the strength requirements, Mr. Westera of the laboratory 'TWELLO' calculated table 2 with the help of some statistical terms and, where necessary, with the findings of Rüsch concerning the mean standard deviation at a certain concrete compressive strength. In table 2 the figures in the last column are to be compared. These figures represent the characteristic compressive strength (5% defective), so the compressive strength of 95% of the blocks is higher than the figure in the last column of table 2.

On basis of the 18 observations the strength results are divided into 4 groups: the group smaller than 22 N/mm^2, the group from 22 to 32 N/mm^2, the group from 32 to 42 N/mm^2 and the group greater than 42 N/mm^2.
The strength requirements, in this case transformed into the characteristic compressive strength of a cube with sides 150 mm, indeed are different!
It would be interesting to determine in the laboratory the flexural strength of concrete blocks from the USA, that just meet the strength

Country	Test	Specimen	Compressive Strength (N/mm^2)		
			Average	Minimum	Characteristic
Australia	compressive	block	-	-	29
	compressive	block	-	-	23
Austria	splitting	block	62	49	-
Belgium	compressive	cube/cylinder	50	42	-
Canada	compressive	cube	42	38	-
Denmark	compressive	2500 mm^2 plates	-	44	-
Finland	flexural	block	-	34	-
France	splitting	block	-	39	49
Germany	compressive	block	40	33	-
Israel	compressive	cylinder	49	40	-
Italy	compressive	block	26	22	-
Japan	compressive	block	35	-	-
The Netherlands	flexural	block	-	-	44
New Zealand	compressive	block	-	44	-
Norway	compressive	2500 mm^2 plates	-	48	-
United Kingdom	compressive	block	27	22	-
USA	compressive	block	33	30	-
	compressive	block	25	23	-

Table 1. 150 mm cube compressive strength ('translated' specification of standard.

Country	Average Compressive Strength (N/mm^2)	S	N	T	Characteristic Compressive Strength (N/mm^2)
USA	25	4.3	3	2.920	13
Italy	26	4.4	8	1.895	18
United Kingdom	27	4.4	16	1.753	19
USA	33	4.6	3	2.920	20
Australia	32	4.2	5	2.132	22
Japan	35	4.7	3	2.920	22
New Zealand	35	4.4	5	2.132	26
Australia	39	4.5	5	2.132	29
Germany	40	4.8	5	2.132	29
Canada	42	4.9	5	2.132	31
Finland	44	4.7	6	2.015	34
Belgium	50	5.2	3	2.920	35
Israel	49	5.2	5	2.132	38
The Netherlands	53	5.0	15	1.762	44
Denmark	76	5.0	2	6.314	44
Norway	80	5.1	2	6.314	48
France	59	5.5	10	1.833	49
Austria	62	5.6	6	2.015	51

Table 2. Real comparison of 150 mm cube characteristic compressive strength.

requirements for non-freeze-thaw regions, and the flexural strength of concrete blocks from Austria, that just meet the Austrian strength requirements.

It was assumed before that an extensive study into the strength requirements would yield some agreement. Even apart from the frequency of sampling (see the figure on page 6 of the Conference Proceedings) the only conclusion can be: it still is a chaos!