ON THE BEARING CAPACITY OF TILE DRAIN PIPES

Rakenteiden Mekaniikka
Vol. 4 No. 1 1971 ss. 4-20; Rakenteiden Mekaniikan Seura, Helsinki

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1. Introduction

The present work is part of research carried out at the Geotechnical Laboratory of the State Institute for Technical Research in Otaniemi to the end of drawing up standards for the draining of structures.

Within the range of the quality control of tile drain pipes a great number of loading tests are being carried out in accordance with the Finnish standard for tile drain pipes RIL 54 b : 1967 [1] (fig. 1a). The aim of the work is to render these test results serviceable in judging the bearing capacity of drain pipes embedded in soil.

A suitable test technique for comparison is the two-edge bearing test which is still used as the standard test technique for drain pipes in Great Britain [2].

The claims for the pipes which appear here can be theoretically compared to the claims on the pipe installed in soil.

2. The pipe's bearing capacity in the crushing test according to RIL 54 b and DIN 1180 : 1962 [3] (fig. 1a)

Here the water-saturated pipes (24 hours, 20°C ± 4°) are laid on two V-formed steel edges at right angles with a bearing distance equal to the pipe's nominal diameter ND. The pipes are then loaded perpendicularly from the top by means of a third edge.

As a predecessor of this test method DIN 1180 : 1931 [4] used wire-coils instead of the steel edges and a constant bearing distance of 250 mm. Zunker 5 found a function to exist between the stress at failure σ_1^* and the load at failure P_1^* as well as the pipe dimensions in the following empiric approximation.

$$\sigma_1^* = \frac{P_1^* \cdot a}{s \cdot d_m} \qquad (1)$$

σ_1^* = stress at failure in wire-coil test, kp/cm^2

P_1^* = load at failure in wire-coil test, kp

a = constant, dimensionless factor

s = wall thickness, cm

d_m = mean diameter, cm

The bearing conditions cause local bending stresses in the ring elements and bring about a many-axial stress state in the drain pipes, though the load is distributed equally over half the circumference.

In the new standard test method [1], [3] the load is applied only at two points. The constant bearing distance, which is equal to the nominal diameter ND of the pipe being tested, produces uncomplicated test technique, but also varying geometrical conditions owing to changing pipe dimensions (outside diameter and s).

Eq. (1) is assumed to be valid also for the new test procedure if only a dimensionless factor c is introduced. An idea of the magnitude of c is obtained by comparing the test results reported by Leusden and Swyter [6], who used a modified wire-coil test technique with the bearing distance being equal to the varying outside diameter of the pipe, to test results reported by Schnellbach [7], which were obtained by the new standard test technique with the bearing distance e = ND.

The factor c can be expressed as a function of s and d_m, both increasing with ND. If c is taken to be

$$c = \frac{d_m}{5{,}5\ s^{4/3}} \qquad (2)$$

the effect of the steel edges is adequately taken into account (fig. 2). The stress at failure is then

$$\sigma_1 = \frac{P_1\ a}{s\ d_m}\ c \qquad (3)$$

σ_1 = stress at failure in standard test, kp/cm²

P_1 = crushing strength in standard test, kp

3. The pipe's bearing capacity in two-edge crushing tests (modified DIN 52 150) [8] (fig. 1b)

The deformations at the top and the bottom of the pipe are a measure for the bearing capacity. These deformations are directly proportional to the stresses according to the theory of elasticity, which is valid for the pipe material in question (see chapter 6).

For the uncomplicated calculation of pipes as a ring area Bach [9] gives a solution for two diametrically applied line loads. This solution can be used in the normal range of s. In the case of symmetric load being applied the maximum bending stresses, determinative in the pipe calculations, occur at the top as well as the bottom of the pipes. In the bending beam theory the stress distribution is taken to be linear, whereas the stress distribution here in the ring area is not linear due to the curved form of the pipes (fig. 3) [10].

$$\sigma_\ell = \frac{3}{\pi} \cdot \frac{P_2 \cdot d_m}{s^2} \qquad (4)$$

σ_ℓ = bending stress for linear stress distribution (straight beam

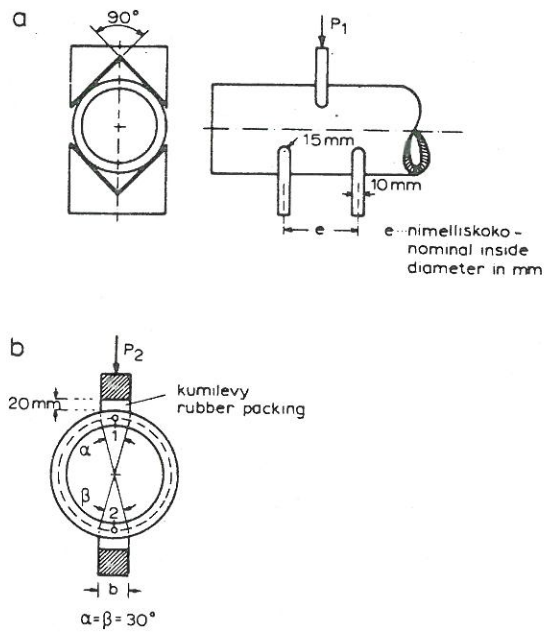


Fig. 1a. Standard crushing test - murtolujuuskoe
RIL 54 b, DIN 1180 : 1962
Fig. 1b. Two-edge bearing test - viivakuormituskoe
$\alpha = \beta = 30^{\circ}$

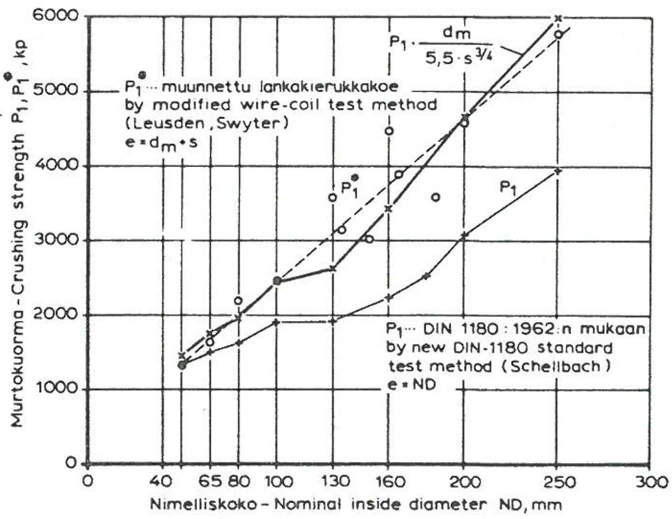


Fig. 2. Influence of point-like load application by means of steel edges as compared to wire-coil bearing.
Pistemäisten kuormitusten vaikutus käyttäen teräslevyjä ja teräslankakierukkaa.

axis), kp/cm²

P_2 = applied line load, kp/cm

$$\sigma_{2\,\substack{\text{inside}\\ \text{outside}}} = \frac{P_2}{2s}\left[-\frac{2}{(1+\kappa)\pi} \pm \frac{2}{(1+\kappa)\pi}\cdot\frac{\frac{s}{d_m}}{\left(1 \pm \frac{s}{d_m}\right)}\right] \qquad (5)$$

σ_2 = bending stress for hyperbolic stress distribution (curved beam axis), kp/cm²

$$\kappa = \sum_{n=1}^{n=\infty} \frac{1}{2n+1}\left(\frac{s}{d_m}\right)^{2n}$$ ... for the cross section at right angles. (6)

$$\xi = \frac{\sigma_2}{\sigma_\ell} = f\left(\frac{s}{d_m}\right)$$ ... ratio of the bending stresses at the inside of the pipe (tab. 1) (7)

Table 1. Ratio of the bending stresses $\xi = \sigma_2/\sigma_\ell$ as function of relative wall thickness $s_p = \frac{s}{d_m}\cdot 100$.
Taivutusjännitysten suhde $\xi = \sigma_2/\sigma_\ell$ suhteellisen seinämäpaksuuden $s_p = \frac{s}{d_m}\cdot 100$ funktiona.

s_p, %	4	6	8	10	15	20	25	30
ξ	1,028	1,042	1,055	1,070	1,105	1,140	1,175	1,215

Fig. 3. Stress distribution for line load - jännityksen jakautuminen viivakuormalla ($\alpha = \beta = 0°$)

The bearing capacity of a pipe depends futhermore on the loading distribution in the upper and the lower halves of the pipe. The horizontal pipe load can be ignored in rigid pipes, which means a higher factor of safety.

In the special case of equal load distribution at the top and the bottom of the pipe ($\alpha = \beta$) we get the same momentums at the top (M_1) and the bottom (M_2). (fig. 1b)

$$M_1 = F_1 \cdot P_2 \cdot \frac{d_m}{2}$$

$$M_2 = F_2 \cdot P_2 \cdot \frac{d_m}{2} \qquad (8)$$

$$\delta_v = F_3 \, \frac{P_2 (d_m/2)^3}{E s^3} \cdot 12 \qquad (9)$$

δ_v = vertical deflection, cm

F_1, F_2, F_3 = $f(\alpha, \beta)$ ... as a graph in (fig. 4) [10]

The angles of the loading distribution α and β depend also on the mean diameter d_m. The load distribution is taken to be perpendicular from the beam edge through the rubber packing to the circumference of the pipe taken at d_m.

For the two-edge bearing test the determinative maximum bending stress at the inside of the pipe is:

$$\sigma_2 = \frac{\xi \cdot F_1 \cdot 3}{33,3} \cdot \frac{P_2' \cdot d_m}{s^2} \qquad (10)$$

$P_2' = \dfrac{P_2 \cdot 33,3}{\ell}$ ... maximum crushing strength per normal pipe length ℓ = 33,3 cm, kp/33,3 cm

ℓ = pipe length, cm

4. <u>Comparison of claims in both test techniques</u>

With the following assumptions, as the modulus of elasticity

E being constant for the pipes compared, the pipe material homogeneous, and the cross-section remaining flat, the stresses can be tàken as a measure for the bearing capacity of the pipe at failure.

$$\sigma_1 = m\sigma_2 \tag{11}$$

$$\frac{P'_2}{P_1} = K \frac{1}{F_1 \cdot \xi \cdot d_m \cdot s^{1/3}} \tag{12}$$

m = proportionality factor

$K = \frac{a}{m \cdot 5{,}5}$ = constant, to be determined from test results.

5. Experimental tests

In the two-edge bearing-test according to DIN 52150 (fig. 1b) edges with b = 2 cm are used for ND $\leq$ 150 mm, and b = 5 cm for larger pipes. Therefore the loading angle varies from 60 to 29 degrees depending on the pipe size. In order to diminish this geometrical influence b was varied in the tests together with ND so as to make $\alpha = \beta = 30^{\circ}$. Thus the constant angle of the load distribution is significant when calculating the pipe's bearing capacity in natural conditions. The load at failure from the two-edge bearing test with $\alpha = \beta = 30^{\circ}$ is represented with the embedding factor $E_Z = 1$ in further calculations (fig. 8).

To remove the unevenness of the pipe wall a 2 cm thick rubber packing was placed between the beam and the pipe's surface. With ND 65 difficulties appeared in the carrying out of the test technique. The pipes slipped under the load when using the rubber packing. By means of a plastic tube (of soft PE) instead of the rubber packing the pipes could be brought to failure. Tests using gypsum between the beam and the pipe wall were carried out as a comparison. They showed, as far as the crushing strength is concerned, that the plastic tube gives the same results.

The two techniques were applied to pipes from three different manufacturers, five nominal diameters were tested with five pipes each. The loads at failure showed, as was to be expected, a greater scatter caused by varying pipe material, burning facility, varying pipe dimensions, ovalness and curvedness.

The mean values of the loads at failure in all the standard tests are approximately 50 % higher than the minimums allowed by the standard (fig. 5a, tab. 2).

The constant K (eq. 12) was obtained from plotting P_2'/P_1 against $10/F_1 \cdot \xi \cdot d_m \cdot s^{1/3}$. A straight line was drawn through the points obtained and through the origin giving K the value K = 2,2. The correlation is reasonable when considering the great scatter of the test results (fig. 6).

Ranta [11] tested Finnish pipes according to British standard 1196 : 1944 with $\alpha = \beta = 0^o$. He tested a ten pipeseries from five different manufacturers ND varying from 40 till 130 mm. His test results showed a good analogy to the mean values here obtained when taking into account the smaller angle of load distribution. Other tests of Ranta according to ASTM standard [12] with sand-filled high pressure hose ($\alpha = \beta = 90^o$) display a similar tendency as the test results here obtained. Only the mean value for the failure load at ND 65 was unexpectedly low (fig. 5b). The tests of Ranta were carried out before the Finnish standard RIL 54 b was published. The dimensions of the pipes used at that time do not in every respect fulfill the requirements set by the standard.

Leusden and Swyter carried out research for a new test method (the new DIN 1180 standard) and in this connection they also made two-edge bearing tests with drain pipes according to DIN 52150 using

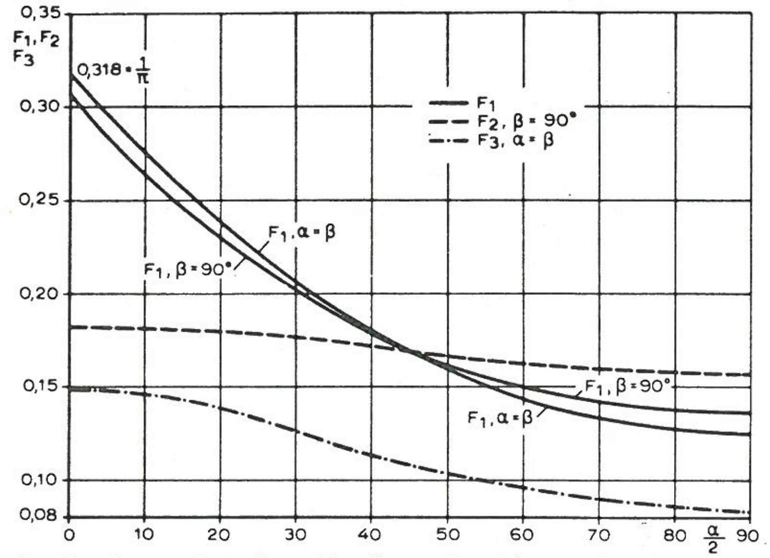


Fig. 4. Factors F_1, F_2, F_3 (eq. 8, 9) as function of loading distribution angles α and β.
Tekijöiden F_1, F_2, F_3 (yht. 8, 9) riippuvuus kuormitusjakautumakulmistä α, β.

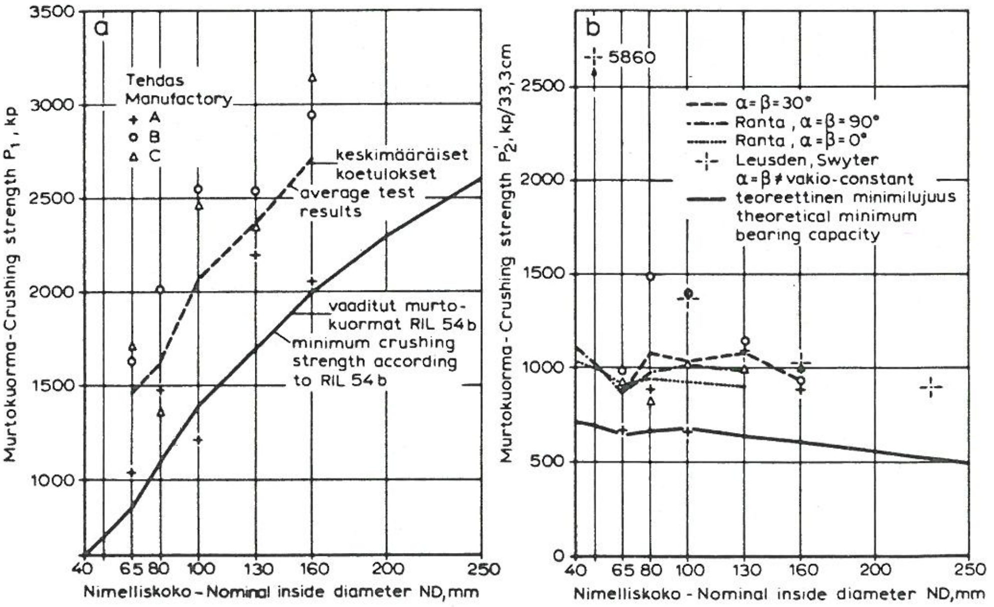


Fig. 5a. Average test results and minimum allowable crushing strength for the standard test method.
Keskimääräiset koetulokset ja sallittu minimilujuus.

Fig. 5b. Average test results for two-edge bearing tests and proposed theoretical minimum bearing capacity for standardised pipes.
Viivakuormituskokeiden keskiarvot ja oletetut teoreettiset minimilujuudet normien mukaisille putkille.

a 2 cm wide beam with ND - 150 mm, a 5 cm wide beam with ND 150 mm, and furthermore using gypsum. We have mean values from 70 tests in all with ND 50, 100, 160 and 230 mm, the pipes being from different manufacturers. Compared to Finnish pipes the bearing capacity was higher, as a rule. An explanation for this can be found when making a comparison between DIN 1180 : 1962 and RIL 54 b. While DIN professes two quality classes, RIL applies corresponding quality class II for ND 40, 50 and 65 mm, class I for ND 100, 130 and 160 mm and the rest of the pipe sizes lying in between. The mean crushing load of 5860 kp for the German 50 mm pipes is thus due to the higher requirements for the quality class I. Furthermore DIN employs smaller pipe diameters and smaller thicknesses, which bears a favorable influence upon the failure in the two-edge bearing test.

Table 1 of RIL 54 b gives the allowable maximum and minimum values for wall thickness and inside diameter of the tile-drain pipes. The combination of maximum inside diameter and maximum wall thickness is unfavorable from the standpoint of the pipe's bearing capacity. For these pipe dimensions and the minimum crushing load allowed by the RIL standard for the standard test method the minimum requirements for the two-edge bearing tests were calculated when $\alpha = \beta = 30^{o}$. The values so obtained were partially not met by pipes from manufactory A and neither do the corresponding pipes come up to the minimum standard failure load. (fig. 5b)

6. Properties of pipe material

Deformation measurements were carried out in the two-edge bearing tests to determine the elastic properties of the pipe material. The stress-strain diagram presented a linear correlation in the most cases till failure. Only in a few cases the diagram was somewhat nonlinear; when treating the curved part of the plot separately the E-modulus decreased with the increasing load (fig. 7)

The measurements were made for pipes with ND 100. 130 and 160 mm. Table 3 shows mean values from measurements with 3 pipes.

From eq. (9) the modulus of elasticity E is

$$E = F_3 \frac{P_2(\frac{1}{2} d_m)^3}{\delta_v s^3} \cdot 12 = \frac{P_2}{\delta_v} K_E \qquad (13)$$

$$K_E = 0{,}75 \; F_3(\frac{d_m}{s}) \qquad (14)$$

K_E = geometrical component, dimensionless.

7. Conclusions

Tile drain pipes, which fulfill the requirements on quality and dimensions set up by the Finnish standard RIL 54 b, will develop a minimum crushing strength in similar embedding conditions as in the two-edge bearing test as given in fig. (5). The claim on the pipe can be compared for different embedding conditions by means of the momentums at pipe top and bottom (fig. 8). E_Z = embedding factor, which points out the importance the careful preparation of the trench bottom or the filter bed has on the pipe's bearing capacity. $0^o < \beta < 60^o$ can be assumed for pipe bed not preformed, $60^o < \beta < 100^o$ is the range for preformed pipe bed [13]. By aid of E_Z the true bearing capacity of the tile drain pipes can be calculated for a chosen factor of safety and for certain embedding conditions.

Table 2. Mean values of crushing strength and scatter for the tests carried out.
Keskimääräiset murtokuormat ja hajonta suoritetuista kokeista.

a) standard test method - koemenetelmä RIL 54 b:n mukaan
crushing strength - murtokuorma, P_1, kp

factory tehdas	nominal inside diameter - nimelliskoko, ND, mm 65	80	100	130	160
A	1038 +102 -213	1478 +122 - 88	1214 +156 -154	2196 +434 -366	2056 +404 -586
B	1630 +100 -105	2011 +219 -326	2548 +332 -223	2539 +206 - 89	2945 +365 -235
C	1712 +268 -242	1358 +132 - 83	2461 +374 -271	2345 +260 -405	3140 +530 -610

b) two-edge bearing test - viivakuormamenetelmä
$\alpha = \beta = 30^{o}$
crushing strength - murtokuorma, P_2', kp/33,3 cm

factory tehdas	nominal inside diameter - nimelliskoko, ND, mm 65	80	100	130	160
A	673 + 54 - 39	890 +139 -218	665 + 97 - 54	1095 +286 -345	892 + 70 - 88
B	983 +205 -121	1486 + 56 -189	1396 +142 -204	1146 + 24 - 60	929 +255 -118
C	930 + 98 -125	845 +202 -228	1029 + 83 -140	1000 +230 -200	1011 +235 -146

Table 3. Average test results from deflection measurements.
Muodonmuutosmittauksista saadut keskimääräiset koe-tulokset.

factory tehdas	ND	$\frac{P_2 \, 10^{-3}}{\delta_v}$	K_E	E
	mm	kp/cm^2	-	kp/cm^2
A	100	51,1	1,64	84 500
	130	45,2	2,99	135 000
	160	40,1	2,12	85 000
B	100	68,2	1,69	115 000
	130	43,6	1,91	83 500
	160	30,4	1,98	60 000
C	100	103,3	1,59	161 000
	130	40,5	2,86	116 000
	160	32,9	2,89	95 000

Table 4. Bearing capacity of standardised tile-drain pipes for different embedding conditions.
Normien mukaisten tiilisalaojaputkien lujuus eri-laisissa asennusolosuhteissa.

P'_2	nominal inside diameter - nimelliskoko, ND, mm								
kp/33,3 cm	40	50	65	80	100	130	160	200	250
E_Z = 1,00	710	690	645	665	675	635	605	550	495
" = 1,10	780	760	710	730	740	700	665	605	545
= 1,36	965	940	875	905	915	865	825	750	675
= 1,66	1180	1145	1070	1100	1120	1050	1000	910	820

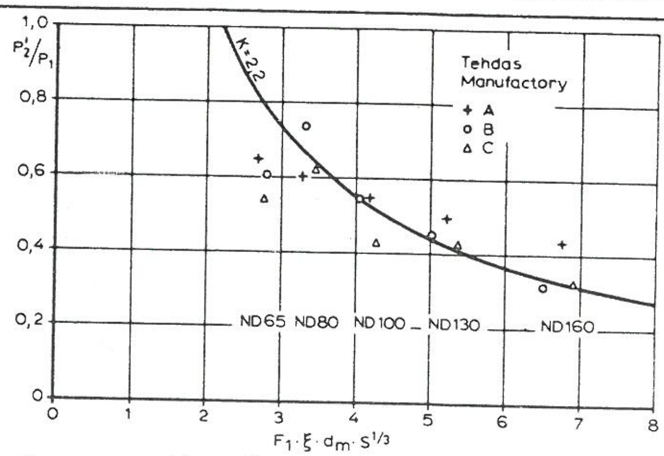


Fig. 6. Mean results of the ratio P_2'/P_1 from crushing tests plotted against $F_1 \cdot \xi \cdot d_m \cdot s^{1/3}$ compared to the theoretical curve with K = 2,2.
Murtokokeista saadut suhteen P_2'/P_1 keskiarvot lausekkeen $F_1 \cdot \xi \cdot d_m \cdot s^{1/3}$ funktiona verrattuna teoreettiseen käyrään K = 2,2.

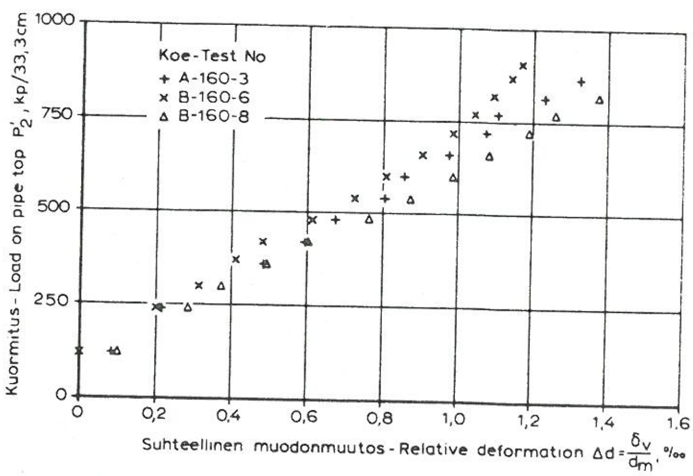
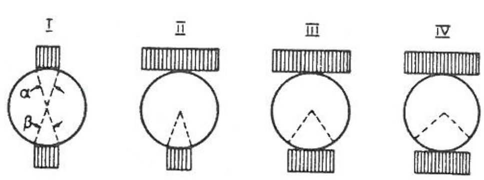


Fig. 7. Deflection curves from three pipes.
Muodonmuutoskäyriä kolmesta putkesta.



	I	II	III	IV
α°	30	180	180	180
β°	30	30	60	90
F_1	0,257	0,148	0,143	0,137
F_2	0,257	0,234	0,189	0,155
E_z	1,00	1,10	1,36	1,66

Fig. 8. Embedding conditions.
Asennusolosuhteet.

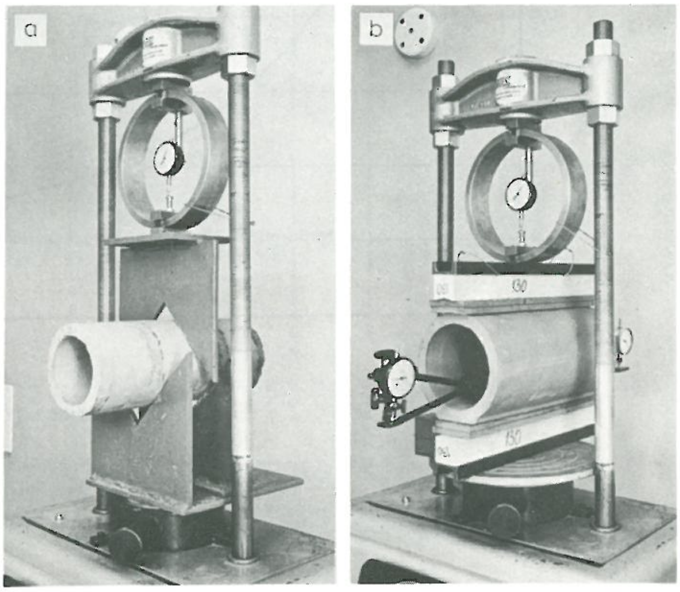


Photo 1. a) Standard crushing test. Normin mukainen koemenetelmä.
b) Two-edge bearing test. Viivakuormamenetelmä.

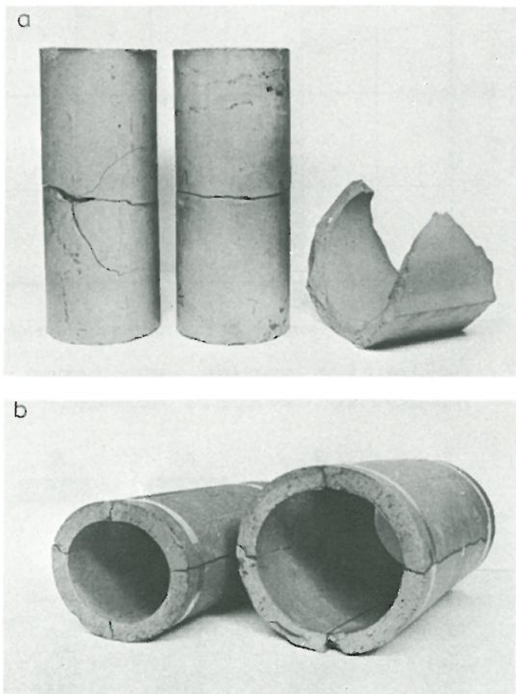


Photo 2. Typical crushing figures. Tyypillisiä murtumia.
a) in standard test. Normin mukaisessa kokeessa.
b) in two-edge bearing test. Viivakuormituskokeessa.

Yhteenveto

Tutkimuksessa on käsitelty maahan asennettujen, RIL 54 b:n mukaisten tiilisalaojaputkien lujuutta. Normissa suositellun koemenettelyn lujuus- ja kuormitusolosuhteet asettavat putkille rasituksia, jotka ovat epätavallisia luonnollisissa asennusolosuhteissa. Muunnetun viivakuormituskokeen avulla putkeen vaikuttavat erilaiset rasitukset saadaan keskenään vertailukelpoisiksi. Suoritetut muodonmuutosmittaukset osoittivat kimmoteorian paikansapitävyyden putkimateriaalille.

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