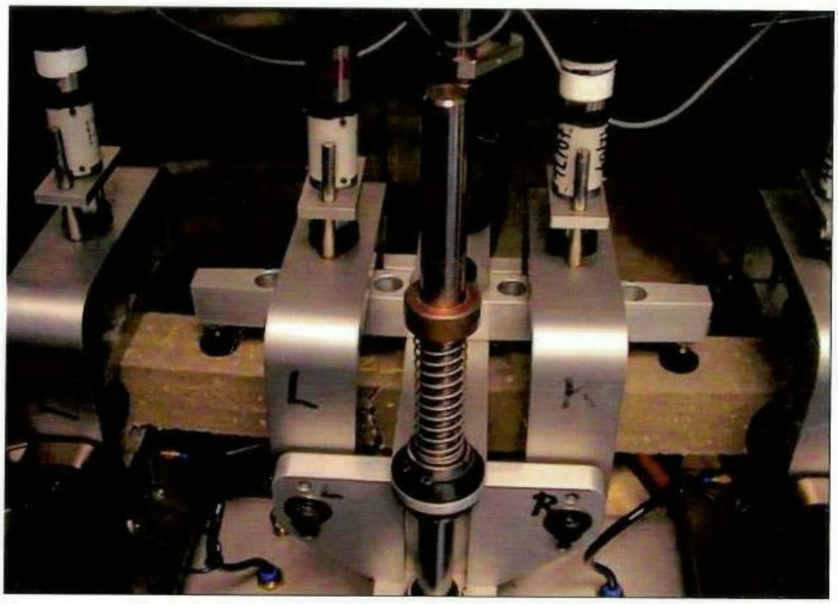
Research in to the bending strength of harbour dredged silt and sand mixtures stabilised with ImmoCem



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Exploratory study into (fatigue) buigtreksterkte of port silt sand mixtures, stabilised with ImmoCem

Rapport 7-08-190-1

Research for PowerCem Technologies LTD. and Arcadis

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1. Introduction

This report presents the results of an exploratory study of the fatigue properties of beams made from a mixture of port silt and sand, stabilised with fly ash cement mixture with additives.

Section 2 of the report presents the information about the testing equipment and describes the details of the calculations used for the determination of the properties of the material studied. All the formulas are given for calculating the mechanical properties (tensile stress , breaking strain, dynamic stiffness.)

Section 3 Presents the detail s of the research carried out with the mixture port silt and sand stabilised with ImmoCem 35/0.3.

The order for the work came with the information regarding the composition of the material to be tested, a summary results of the 3-point load cell tests carried out and the results of these tests as provided by KOAC-NPC, the relevant data (dimension and compactness) of the 4 beams supplied for the tests, and the results of the (fatigue) bend tests on the 4 beams.

During the research the actual procedures for the tests were modified in light of the results that have been obtained.

In section 4 the similar research on port silt sand mixture with ImmoCem 35/3,0 binder is presented.

In section 5 the results of 2 2 point load cell tests on silt sand 50/50 stabilised with ImmoCem are given. Finally in section 6 conclusions of this exploratory research are presented.

In the appendices relevant measurement results of each test are given graphically including the photographs taken during the actual tests.

2. Equipment

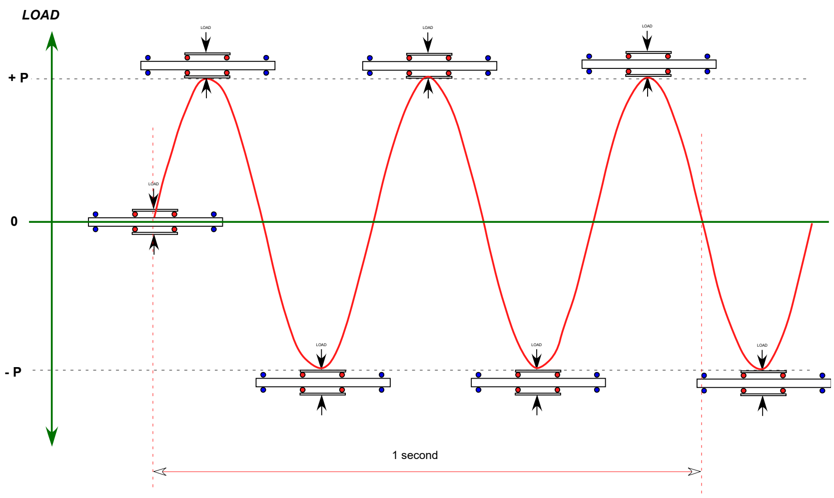
In this research fatigue at failure tests on the test beams have been carried out with 4-points bending test cell as well as with the 2 point bending test cells.. The test cells and other equipment used as well as the mathematical formulas used in the calculation of material properties are presented below.

<u>2.1. Fatigue tests with 4-points bending cell equipment</u>

The fatigue tests on the test beams have been carried out using a 4-point bending cell equipment with pneumatic loading mechanism (UTM equipment - figure 1). The fatigue tests have been carried out under testing regime/conditions commonly used for cement-bound materials. The tests have been done at a constant temperature of 20 degrees and a load application frequency of 5 Hz. The applied loading is a pure sine wave, meaning that the test beam deflection(bending) occurs simultaneously on the top and bottom surface thus preventing permanent deformation during the duration of the fatigue test.

Figure 1. UTM 4 point bending test cell for fatigue measurement (with the test piece made with ImmoCem 35/0,3)

During fatigue test a *sine* shaped loading wave is applied, and therefore a *sine* shaped bending and compression and tension at the bottom and the op of the test beam are applied.



To maximum bending tension □ at the base of the beam has been determined beforehand as a function of Load P in equation (1):

$$= \; . \; \times \; \frac{}{\times} \rightarrow \; = \times \; \times \frac{}{. \times}$$ 1

Where

= **applied load(N)**

= **(N/mm²)**

=**width of the test beam (mm)**

= **height of the test beam (mm)**

= **distance between loading points and support points (=118.5 mm)**

The maximum tensile strain at the middle point of the beam is a function of maximu deflection at that point and is given by equation 2

$$= \; \times \; \times \frac{}{}$$ 2

where

= **maximum deflection at middle point of the beam, mm**

= **maximum strain, m/m**

The Dynamic Stiffness Modulus, S is calculated using the formulae:

$$= \frac{}{}$$ 3

With bituminous material it is usual to consider the failure of the test beam occurring when the dynamic stiffness modulus S has decreased to 50% of the initial value at the beginning of the test (The initial value for the dynamic stiffness modulus is considered to be the value of S which occurs during the first 100 cycles of loading application).

2.2 Breaking tests with 4-points bending cell equipment

The breaking tests on the test beams have where carried out with 4-points load cell in pneumatic UTM-equipment (Figure 2). These tests where also used to determine the strength of the test (constant increase of the strength by unit of time), at a constant temperature of 20 degrees.

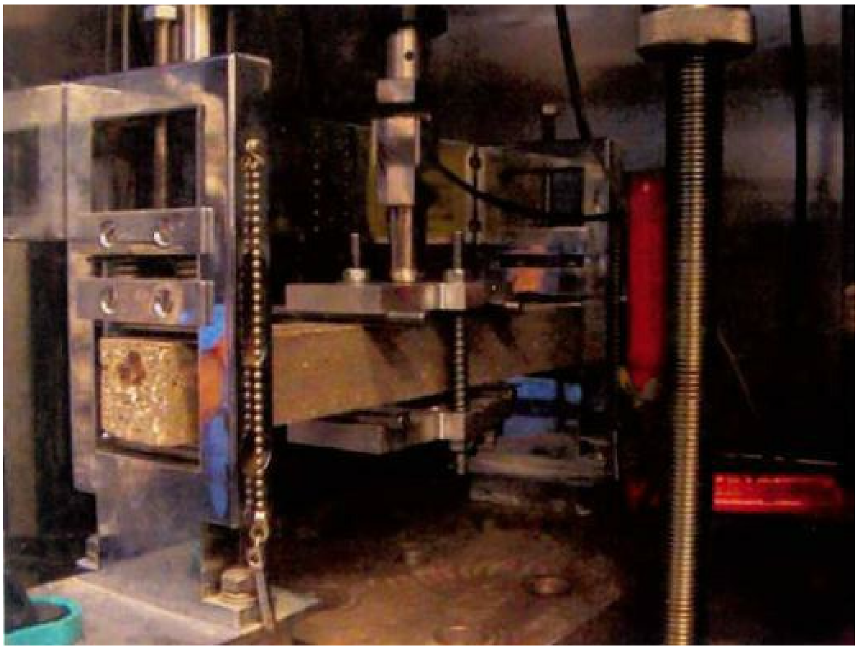


Figure 2. 4-points load cell equipment as used in the tests in UTM-elaboration (the test beam shown was produced with ImmoCem 35/0,3)

The tensile stress (maximum stress at the base of the beam) follows P_{max} as measured during the test:

$$= \times \frac{}{\times} \rightarrow = \times \times \frac{}{. \times} \qquad (4)$$

Where

= **Load at failure(N)**

= **breaking stress at bottom of the beam(N/mm^2)**

=**width of the test beam (mm)**

= **height of the test beam (mm)**

= **distance between the loading points(=133.33 mm)**

The maximum tensile strain at the middle point of the beam is a function of maximum deflection at that point and is given by equation 5

$$= . \times \times \times \frac{}{} \qquad (5)$$

where

= **deflection, mm**

= **strain, m/m**

The Dynamic Stiffness Modulus, S_b is calculated using equation below:

$$= \frac{□}{} \qquad 6$$

2.3. Breaking tests with 2-point Load Cell Equipment

The 2-points breaking tests have been carried out in the pneumatic UTM equipment (figure 3). The test beams are glued on a steel block-system that are clumped on the steel bottom plate of the UTM equipment. Also these breaking tests were used to determine the strength of the specimen (constant increase of the strength by unit of time), at a constant temperature of 20 degrees. Aside from the strength the displacement of the test beam t.p.v. the gripping point at a given load is also measured with 2 LVDT's.

The breaking stress at a maximum load is given as:

$$□ = \times \frac{}{\times □} \rightarrow = □□ \times \times \frac{□}{\times} \qquad 7$$

Where

= **(N)**

□ = **stress at bottom of the beam at failure (N/mm^2)**

=**width of the test beam (mm)**

□ = **height of the test beam (mm)**

= **See table 7 for appropriate value (distance between the support point and the point of load application)**

The breaking strain is than given by equation 8

$$= \; . \times \quad \times \frac{□}{} \qquad 8$$

where

= ,

= **breaking strain at failure, m/m**

The Dynamic Stiffness Modulus, S_b is calculated using the formulae:

$$_b = □□ / \varepsilon_b \qquad 9$$

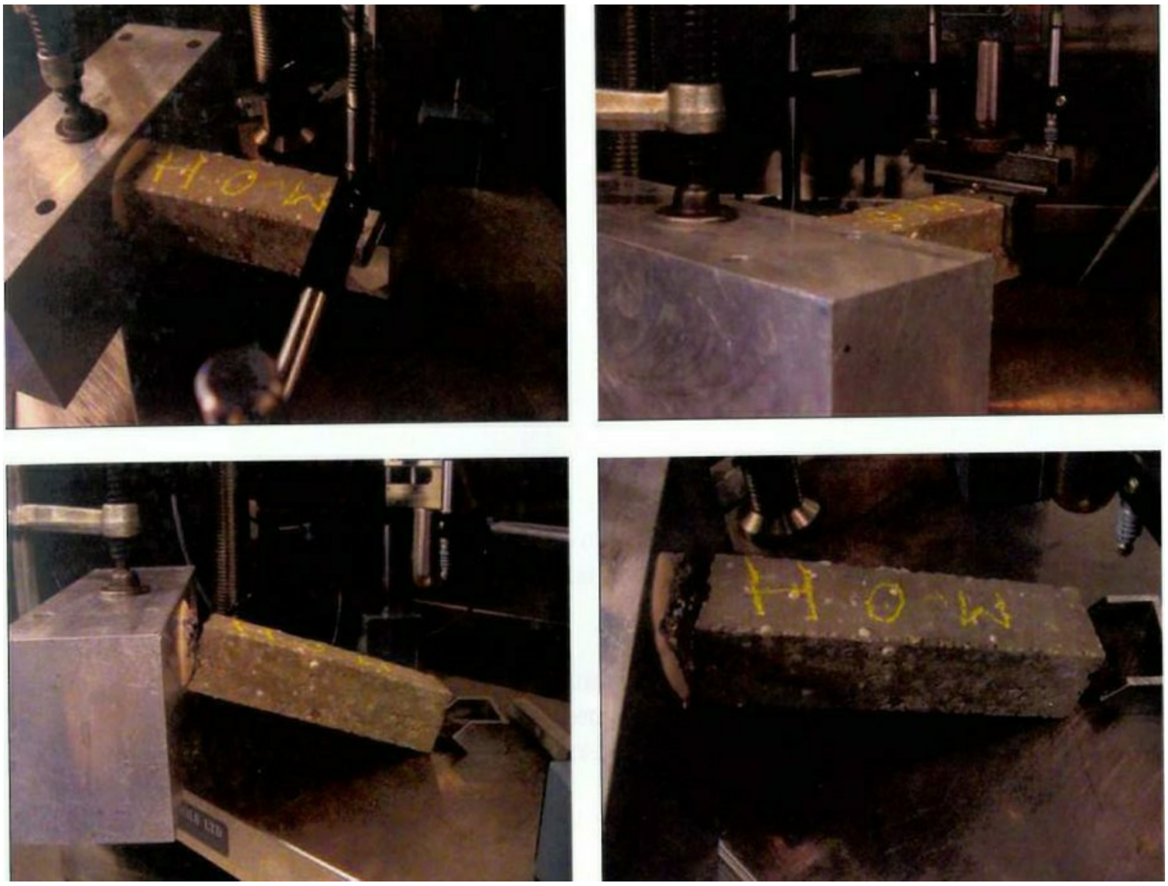


Figure 3. 2-Equipment and test cell used for 2 point tests

3. 4-points load cell tests on ImmoCem 35/0.3 samples

3.1. Material

The specimen beams for the tests were prepared as follows:

50% (m/m) ports silt,

50% (m/m) sort sand (sieved on 0.8 mm)

The above were combined and mixed well and then the binder consisting of :

30% (m/m) fly ash

0.3 % (m/m) ImmoCem

65 % (m/m) Cement CEM I 52.5 R

4.7 % (m/m) Chalk (CaO)

at a dose of 35 % (m/m) resulting in the following mix specification (m/m):

Ports silt 37.00 %,

Sort sand (sieved on 0.8 mm) 37.00 %

Fly ash 7.80%

ImmoCem 0.08 %

Cement CEM I 52.5 R 16.90 %

Chalk (CaO) 1.22 %

3.2.Previous Research by KOAC-NPC

KOAC-NPC carried out investigation on 3 beams, manufactured on 22-1-2008 in steel gage forms, with dimensions of 500* 100* 100 mm (length * width * height). These test beams were used to determine:

- **Compactness (Density)**
- **Elastic modulus, measured with concrete tester**
- **Braking strain using a 3 point loading cell (length 300 mm) and an increase of the loading at a rate of 0.075 MPa per second.**

The tests were carried out on 21-2-2008. The results are shown in table 1. Note the very large breaking strain at failure.

Specimen (Sample beam)	Density, kg/m^3	Dynamic Stiffness, MPa	Tensile stress, MPa	Braking Strain [redacted]
A	1520	4634	1.50	2054
B	1514	4522	1.63	1980
C	1522	4975	1.81	2114

Table 1. Results of the tests carried out by KOAC-NPC

3.3.Preparation of Specimens

The test specimens (beams) were prepared on the on 22-1-2008 in the standard steel moulds. The dimensions of test beams were 500 * 100 * 100 mm (length*width*height. Three of the beams were taken to KOAC-NPC and one of the beams was supplied to TU-Delft on 11-4-2008 for further testing.

On 14-4-2008 the test beam supplied was cut by a diamond saw to 4 test pieces for fatigue tests using 4 point load cell at TU Delft. The information of the fatigue test specimens is given in table 2 below:

Specimen	Location on the original sample	Length, mm	Width, mm	Height, mm	Half day after sawing		23.06.2008	
					Weight, g	Semi wet Density. Kg/m3	Weight, gr	Dry Density. Kg/m3
1	top	449	47.69	46.31	1589.6	1603	1433.7	1446
2	top	449	46.90	46.19	1558.8	1603	1410.3	1450
3	bottom	449	47.88	47.73	1652.1	1610	1493.5	1456
4	bottom	449	46.47	47.92	1615.1	1616	1462.1	1462

Table 2. Test specimens – ImmoCem 35/0.3

Note: Semi wet density was determined 0.5 days after sawing the samples and they were still wet but not necessarily saturated with water. Dry density was determined 70 days after cutting and drying at room temperature. As can be seen during cutting the samples absorbed about 10.5 % (m/m) of moisture. It can thus be concluded that the samples have a tendency to absorb moisture and it should be stressed that the effects of the moisture absorption on fatigue behaviour have not been tested in this research. The density at the time of KOAC-NPC tests was not measured.

3.4.Test results

The first fatigue test has been carried out on test piece 4, where maximum tensile stress at the base of the beam of 0.9 MPa has been imposed (60% of the tensile stress at failure for the weakest of 3 beams tested by

KOAC-NPC, see table 1).

The change of the dynamic stiffness modulus with time (and number of load applications with a defined frequency N), S, is shown graphically in Appendix 1. Photographs of brittle failure of test pieces are also shown.

At the failure surface bits of plastic and a bit of glass, which contributed to this failure point are visible.

The initial stiffness modulus (at N = 100 load changes) amounts to 3808 MPa. The test piece failed after an amazing 14520 load applications and at a time of failure the stiffness modulus was reduced 2440 MPa. The initial strain observed was 236 um/m and the strain at failure was 369 um/m.

The gradual reduction of the dynamic stiffness modulus S does more resemble the behaviour of bituminous bound material (asphalt) and is not typical of a normal cement bound material (concrete)!

Because of the unexpectedly small number of load applications before the failure occurred for test peace number 4 it was decided to, for subsequent tests first carry out a monotonous 4-point failure test on 1 test piece for in order to determine the value of the tensile stress at failure.

During the tests carried out by KOAC-NPC the loading during the test was applied at a rate of 163 N/s until failure. This corresponds to an increase of tensile stress of more than 0.075 MPa per second.

Since the fatigue tests carried on test piece 4 showed that the material resembles the behaviour of bituminous bound material and due to the fact that for bituminous material the tensile stresses are lower if the test is carried out more slowly it was decided that, for test piece number 1, the fatigue tests should be carried out with decreased rate of loading of 0.038 MPa per second, a decrease of the rate of loading by a factor of 2, and corresponding to a rate of loading of 9.6 N/sec. In this manner the tensile stress and strain at failure are tested under most unfavourable test conditions.

In appendix 2 photographs specimens at failure and the test results are presented (stress and displacement as a function of time until failure. The test piece has failed at a load of 480 N when vertical displacement 0.56 mm was observed. Equation 4 was then used to calculate the breaking tensile stress of 1.88 MPa and the and equation 5 to calculate the breaking strain of 875 um/m.

The measured tensile stress is therefore, despite a smaller rate of loading increase per unit time, still somewhat higher than was observed by KOAC-NPC when testing larger beams with 3-point load cell.

On the other hand the measured strain at failure observed was much smaller than measured by KOAC-NPC (to see table 1).

The stiffness modulus at failure, Sb (equation 6) as observe was 1,88/0,000875=2150 MPa and this is approximately 12% lower than the stiffness modulus at the end of the fatigue test on test piece 4 (2440 Mpa, see table 3).

Related to these is the measured tensile stress for test piece 4 (0.900 MPa) which is 48 % of the tensile stress at failure.

Then a fatigue test was carried out on test piece number 2. Considering the result of the fatigue test on test piece number 4 it was decided to apply a lower tension at the bottom of the test beam of 0.752 MPa for the fatigue test of test beam number 2 and this corresponds to 40% of tension applied during fatigue test of test beam number 1.

On the basis of the 2 earlier test results, and taking into consideration the fatigue behaviour of normal cement bound materials, a number of load applications before failure was expected to reach 100000.

The surprising result was that test piece 2 failed after 614230 load applications. The change of the dynamic stiffness modulus, S, as a function of a number of load applications N is presented in appendix 3 which also shows a photograph of the test beam at failure.

The initial stiffness modulus was 5242 MPa (this was 38% higher than the initial stiffness modulus of test piece 4). The stiffness modulus at failure was reduced to 3660 MPa. In spite of some unexplainable temporary increases of stiffness modulus the gradual decrease of the dynamic stiffness modulus, S, is evident. The initial strain was 143 un/m and the strain at failure was 205 um/m.

Given the unexpectedly good result of the fatigue test on test piece 2 leads one to conclusion that test piece number 4 was just a bad sample. For this reason it has been decided that the last available test piece for the fatigue test (test piece number 3) be submitted to the same test conditions as the test piece number 4, i.e tensile stress of 0.900 MPa.

The change of the dynamic stiffness modulus, S, as a function of the number of load applications is shown in appendix 4. The initial stiffness modulus was 5364 MPa, which corresponds to an initial strain of of 168 um/m.

During the test the dynamic stiffness modulus has remained virtually constant, in other words no fatigue damage has been observed. After 2905760 load cycles the fatigue test was stopped because it was not to be expected that the test piece would fail ever compared with the imposed tensile stress of 0.900

Test Specimen	Density as observed on 23.06.2008, kg/m3	Date of testing	Observed maximum tensile stress at failure MPa	Initial stiffness modulus Si, MPa	Initial strain, um/m	Number of load cycles applied	Stiffness Modulus at failure, MPa	Ratio of Stiffness at failure to Initial Stiffness, %
1	1446	8.5.2008	Tensile stress 1.88 MPa, strain at failure 875 um/m					
2	1450	13.5.2008 to 15.5.2008	0.752 (40%)*	5242	143	61423	3660	70
3	1456	15.5.2008 to 22.5.2008	0.900 (485)*	5364	168	Sample did not fail after 2905760 cycles, stiffness modulus at termination of the test was S= 5200 MPa		
		22.5.2008 to 26.5.2008	1.316 (70%)*	5196	253	Sample did not fail after 1713220 cycles, stiffness modulus at termination of the test was S= 4900 MPa		
		26.5.2008 to 27.5.2008	1.598 (85%)*	4893	327	377530	3380	63
4	1462	22.4.2008	0.900 (40%)*	3808	236	14520	2440	64

Table 3. Results of the fatigue tests on ImmoCem 35/0.3 samples

At this point it was decided to continue the fatigue test of test piece 3 with a higher tension level, namely tensile stress of 1.316 MPa, which corresponds to 70% of the breaking tensile stress of test piece 1. The initial elasticity modulus amounted to 5196 MPa (therefore the same value as at the end of the test with 0.900 MPa) and the initial strain was therefore 253um/m.

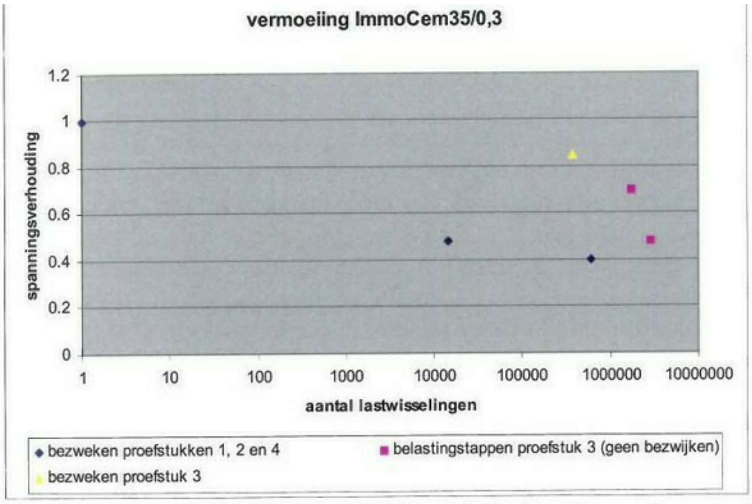
As can be seen from figure 2 of appendix 4 at this tension level the dynamic stiffness modulus remains, virtually constant and therefore no further damage development appears. For this reason this test was stopped after 1713220 load cycles, when the dynamic elasticity modulus of 4900 MPa was observed.

Test piece 3 was than subjected tests with tensile stress of 1.598 MPa, corresponding to 85% of the breaking tensile stress of test piece 1. The initial elasticity modulus was now 4893 MPa (therefore the same value as at the end of the test with 1.316 MPa) and the initial strain was therefore 327 um/m. From figure 3 of appendix 4 the dynamic stiffness observed gradually decreases until eventually, after 377530 load cycles, a rather brittle failure appears. At failure the dynamic stiffness modulus had decreased to 3380 MPa, corresponding to 63% of the original initial value of 5364 MPa. The results of the fatigue test on test piece 3 indicate that the tensile stress at failure of this test piece was considerably larger than the measured tensile stress at failure for test piece1, to which the applied tensile stresses in this research are related. In appendix 4 a photograph is presented which shows of the test piece 3 at failure in 4-point load cell tests.

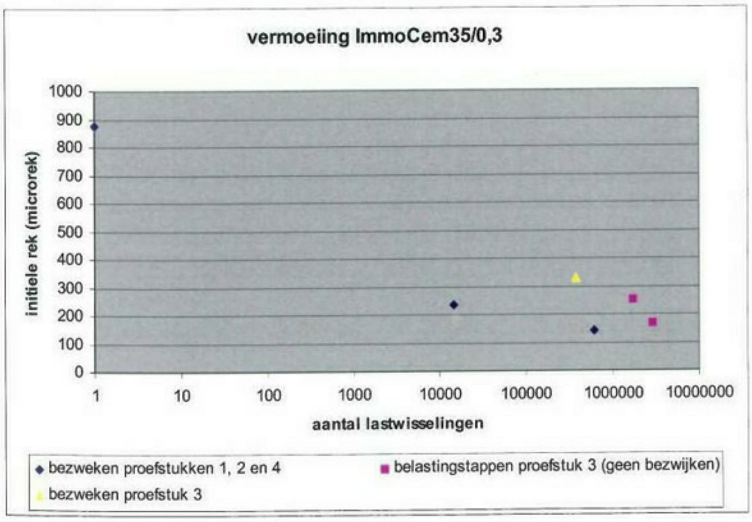
The results of the fatigue and failure tests are summarised in table 3.

The results of the research have been graphically presented in 2 different ways. In figure 4 the number of load cycles (up to failure) is plotted on a logarithmic scale, against the proportion of the applied tensile stresses as measured by the tensile breaking stress for test piece number 1.. In figure 5 the number of load cycles (up to failure) is again plotted on logarithmic scale, against the initial strain (after 100 load cycles).

Information presented in figures 4 and 5 must be considered in light of the fact that the first 2 load cycles on test piece 3 (purple point) did not contribute to the failure of the test piece. Because of the very large spread of the test results the regression analysis for the determination of a fatigue line has not been performed.



Figuur 4. Aantal lastwisselingen (tot breuk) als functie van de spanningsverhouding (ratio van opgelegde buigtrekspanning en buigtreksterkte van proefstuk 1) voor ImmoCem 35/0,3.



Figuur 5. Aantal lastwisselingen (tot breuk) als functie van de initiële rek voor ImmoCem 35/0,3.

4. 4 point and 2 pint bending tests on samples prepared with ImmoCem 35/3,0

4.1 Material

The specimen beams for the tests were prepared as follows:

50% (m/m) ports silt,

50% (m/m) sort sand (sieved on 0.8 mm)

The above were combined and mixed well and then the binder consisting of :

32% (m/m) fly ash

3.0 % (m/m) ImmoCem

65 % (m/m) Cement CEM I 52.5 R

at a dose of 35 % (m/m) was added):

4.2 Test pieces

The sample beams with the above mix were prepared on 12-5-2008 (500*100*100 mm) in steel moulds and provided to TU Delft research team on 28-5-2008. On 9-6-2008, at the age of 28 days the test beam was cut into 4 test pieces for the fatigue research with 4-point load cell. The location of the test pieces on the original beam was recorded.

The density of the test pieces immediately after cutting ranged from 1447 to 1465 kg/m3. After 14 days of drying the density ranged 1375 up to 1406 kg/m3. It is noted that the density of the two sample pieces from the top side of the original beam was 30 kg/m3 higher than the density of the two test pieces from the bottom of the original beam.

Comparison of the densities of the ImmoCem 35/0,3 test pieces with the density of ImmoCem 35/3,0 test pieces (table 2) shows that the later are significantly lower. The reason for this is the presence of higher amount of polystyrene granules in the second set of samples.

Specimen	Location on the original sample	Length, mm	Width, mm	Height, mm	Half day after sawing		23.06.2008	
					Weight, g	Semi wet Density. Kg/m3	Weight, gr	Dry Density. Kg/m3
1	top	451.00	47.12	48.14	1498.40	1465	1438.20	1406
2	top	450.50	47.93	48.14	1522.40	1465	1461.50	1406
3	bottom	450.50	47.22	47.07	1448.8	1447	1378.20	1376
4	bottom	451.00	47.68	47.32	1476.30	1451	1399.10	1375

Table 4. Dimension and compactness of the test pieces ImmoCem 35/3,0.

On 23-6-2008 breaking strength tests with 4-points load cell were carried out on test piece 3 of the ImmoCem 35/3,0 material. Similarly as before the rate of increase of the strain at the bottom of the test piece of 0.038 MPa per second was applied corresponding to the rate of load increase of 9.94 N per second. Appendix 5 contains the results of the tests carried out as well as the photograph of the test piece at failure. The test piece failed at the load of 464 N which resulted in the vertical displacement 0.62 mm.

The calculated stress at failure using equation 4 was 1.77 MPa and the strain at failure (equation 5) was 985 um/m. The stiffness modulus at failure (equation 6) was calculated as 1795 MPa. The observed breaking tension stress was therefore smaller than that measured for the samples with ImmoCem 35/0,3

However, this time the failure occurred on the top of the test piece in the proximity of 80% of the breadth of the sample and the failure was more or less horizontal (see appendix 5). This in effect reduced the effective height of the test piece from 47.07 mm to only 40 mm.

Taking this into consideration and correcting for it results in tension stress at failure of 2.46 MPa and strain at failure of 837 um/m with the corresponding stiffness modulus of 2940 MPa. These corrected values are used in determining the test condition for the fatigue tests of the remaining 3 test pieces.

On 23-6-2008 the 1st fatigue test in 4-points load cell was carried out on test piece 2. Rather high tensile stresses at the bottom of the test piece of 1.8424 MPa have been applied corresponding to 75% of the measured and corrected tensile stress at failure. Test piece 2 failed rapidly after only 25 load applications (cycles). The progression of the dynamic stiffness modulus during the fatigue is shown graphically in appendix 6 as is a photograph of the failure plane of the test piece. It should be noted that a large number of clean stones in the failure plain have been observed indicating that these were not attached to the binder and this has obviously contributed to the poor fatigue behaviour of this test piece. The initial stiffness modulus (at 10th load cycle) was 4530 MPa. This was reduced to 4370 MPa at failure (20th the load cycle). The initial strain observed 816 um/m and the strain at failure was 841 um/m.

On the 23-6-2008 a 2nd fatigue test in 4-points load cell was carried out on test piece 1. The applied tensile stress (to the base of the beam) was reduced to 1,23 MPa, 50% of the value for test piece 3. Test piece 1 failed after 59360 load cycles. The progression of the dynamic stiffness modulus S with the cyclic load application is shown graphically in appendix 7 which also shows a photograph of the failed test piece. The initial stiffness modulus was 5243 MPa. The stiffness modulus at failure was 3440 MPa. The initial strain was 471 um/m and the strain at failure was observed as 715 um/m.

The 3rd fatigue test in 4-points load cell was carried out on test piece 4 was carried out on 24-6-2008. Same loading conditions as for the 2nd fatigue test were used (tensile stress of 1,23 MPa). Test piece 4 failed after 7050 load cycles. The progression of the dynamic stiffness modulus S with the cyclic load application is shown graphically in appendix 8 which also shows a photograph of the failed test piece. The initial stiffness modulus was 4016 MPa. The stiffness modulus at failure was 2850 MPa. The initial strain was 611 um/m and the strain at failure was observed as 858 um/m.

Sample	Length, mm	Width, mm	Height, mm	As observed on 8.07.2008	
				Weight, g	Density, kg/m3
2a	159.4	47.40	47.50	501.80	1398
2b	159.3	48.80	47.80	513.1	1404

Table 5. Dimensions and density of the test pieces of beam 2 used for 2 point load cell tests

Following the completion of the fatigue tests with 4 point load cell the pieces of the beams that remained after the tests were used for the tests with 2 point load cell. These tests were first carried on the remainder of the test piece number 2 on 24-6-2008. Test pieces with a length of approximately 160 mm were prepared The edges at which failure occurred in the previous tests were removed in the process. When the samples

were 57 days old on the 8-7-2008 failure tests with the 2 point load cell were carried out. Table 5 shows the data about the test pieces that were used in these tests. It should be noted that the density of the test pieces was virtually the same as in the previous tests (Table 4).

Sample	Length, mm	Tensile stress, MPa	Strain at failure, um/m	Stiffness Modulus at failure, MPa
2a	149.00	2.64	1008	2620
2b	149.00	2.46	911	2700

Table 6. Results for 2-points load cell failure tests on ImmoCem 35/3,0 test pieces 2a and 2b.

Similarly as before during the 4 point load cell tests with ImmoCem 35/0.3 for the 2 point load cell tests tensile stress rate of increase of 0.038 MPa per second was applied. Equation 7 can be used to calculate the corresponding rate of load increase in N/second using the information provided in table 5 and table 6. For the test piece 2a this results in the load application rate of 4.55 N/second and for test piece 2b of 4.66 N/second.

Appendices 9 and 10 present the test results in graphical format. Equation 7 was used to calculate tensile stress, strain and displacement at failure and this is shown in Table 6. The results obtained are similar to the results obtained from the 4 point load cell tests done previously on test piece number 3.

The results of the fatigue at failure tests are summarised in table 7.

Test Specimen	Density as observed on 23.06.2008, kg/m3	Date of testing	Observed maximum tensile stress at failure MPa	Initial stiffness modulus Si, MPa	Initial strain, um/m	Number of load cycles applied	Stiffness Modulus at failure, MPa	Ratio of Stiffness at failure to Initial Stiffness, %
1	1406*	8.5.2008	1.23 (50%)***	5243	471	59360	3440	66
2	1406*	23.6.2008	1.8244 (75%)***	4530	816	Ca 25	Knot known	-
2a	1398**	8.7.2008	2 point load cell Tensile stress= 2.64 MPa, strain at failure = 1008 um/m					
2b	1404**	8.7.2008	2 point load cell Tensile stress= 2.64 MPa, strain at failure = 911 um/m					
3	1376*	23.6.2008	4 point load cell Tensile stress= 2.64 MPa, strain at failure = 837 um/m					
4	1375*	24.6.2008	1.23 (50%)***	4016	611	7050	2850	71

*** Density determined on 23.06.2008**

**** Density determined on 8.7.2008**

***** Percentage of correction tests on sample 3**

Table 7. Results of the fatigue tests for ImmoCem 35/3.0 samples

The results of the fatigue tests are presented graphically in two different ways. In Figure 6 the number of load cycles on a logarithmic scale is plotted against the proportion of the applied tensile stress relative to the tensile stress at failure for test piece number 3.

In Figure 7 the number of load cycles until failure is plotted on a logarithmic scale, against the initial strain after 100 load cycles. As before dispersion of the results prevents the application of regression analysis to establish a formal fatigue line.

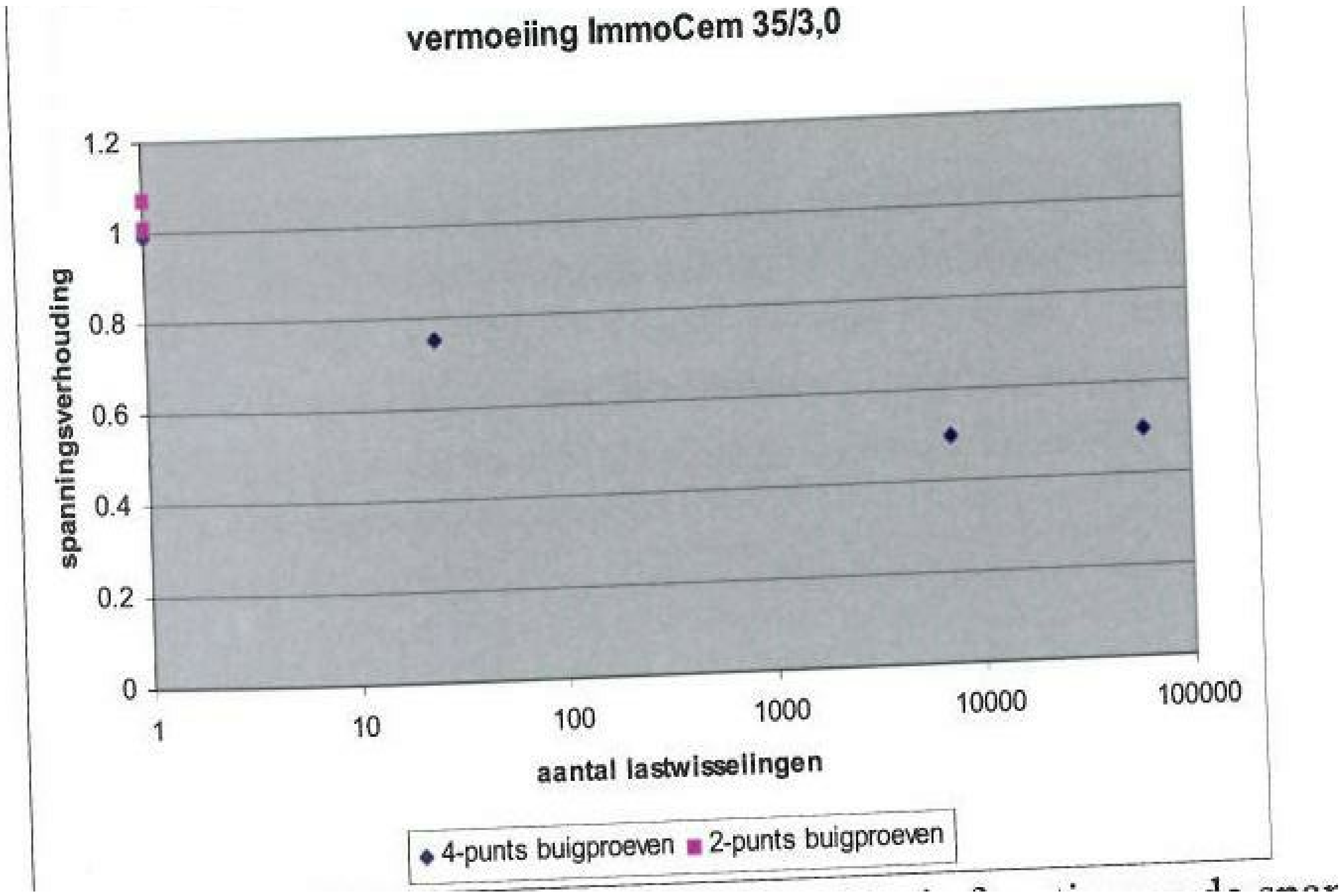


Figure 6. Number of load cycles to failure as a function of the tensile stress as proportion of the tensile stress at failure for specimen for ImmoCem 35/3,0.

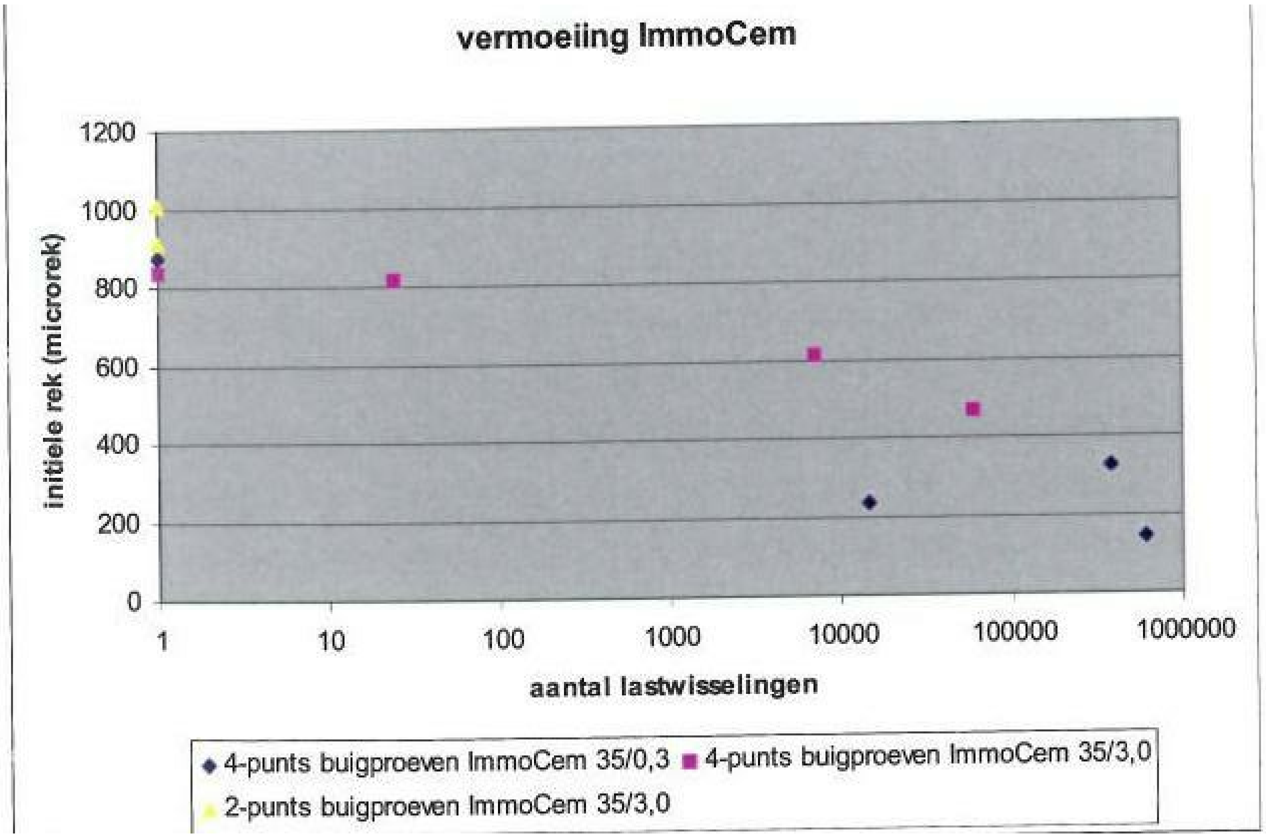


Figure 7 7. Number of load cycles o failure as a function of the initial strain for ImmoCem 35/3,0.

Finally in Figure 8 the number of load cycles to failure is plotted against the initial strain for the two examined materials.

Figure 8. Number of load cycles to failure as a function of the initial strain for ImmoCem 35/0,3 and ImmoCem 35/3,0.

On the basis of the very limited number of fatigue tests carried out no definite conclusions can be made but there seems to be a relationship between initial strain and a number of load cycles to failure that a material can handle. It is also apparent that this number of load cycles to failure is higher for ImmoCem 35/3.0 than it is for ImmoCem 35/0.3 samples..

5. 2-point load cell tests on silt sand 50/50

This section presents the results of the tests carried on the samples produced with the mixture of 50% port silt and 50% sand and stabilized with Cement and ImmoCem. Test beams produced on 12.5.2008. were brought to the lab for tests to be carried out on the 28-5-2008 2. The requested for for tensile stress and strain at failure using a 2 point load test cell. The dimensions and density of test beams provided are shown in table 8.

Specimen	Length, mm	Width, mm	Height, mm	As measured on 23.6.2008	
				Weight, g	Density, kg/m3
F	157.88	39.50	39.87	349.5	1406
H	157.95	39.60	40.53	357.7	1411

Table 8. Dimensions and compactness of the test pieces of silt sand 50/50.

The required tests were carried out using the 2-points load test on 23-6-2008. The age of test samples at the time of the tests was 42 days.

Similarly as before during the 4 point load cell tests with ImmoCem 35/0.3 for the 2 point load cell tests tensile stress rate of increase of 0.038 MPa per second was applied. Equation 7 can be used to calculate the corresponding rate of load increase in N/second using the information provided in table 8 and table 9. For the test piece F this results in the load application rate of 2.69 N/second and for test piece H of 2.77 N/second.

Appendices 11 and 12 show photographs of the area of failure of the two specimens tested. The test results are also shown. Using equations 7 to 9 relevant material properties have been calculated and are shown in table 9.

It should be noted that the observed displacement for sample H is highelly irregular and we can not offer any explanation for this. The calculated strain at failure and stiffness modulus are based on an extrapolation of a linear part of the displacement graph observed during the first part of the test carried out.

Sample	Length, mm	Tensile stress, MPa	Strain at failure, um/m	Stiffness Modulus at failure, MPa
F	148.00	2.57	879	2925
H	148.50	2.73	745	3665

Table 9. Results 2-points load cell tests on silt sand 50/50.

From the tables 8 and 9 it is clear that the variation in density and failure properties for 2 test pieces is limiting more conclusive analysis.

FINDINGS AND CONCLUSIONS

The findings presented in this report are a result of research carried out at the laboratories of TU Delft on fatigue and strength characteristics of sample beams prepared with cement and an additive ImmoCem at two different concentrations (0.3% ImmoCem and 3% ImmoCem as mass of cement used).

Four test beams for each ImmoCem concentration were prepared by cutting up a single larger test beam.

On the basis of the results obtained during the tests the following conclusions can be made:

1. **For the ImmoCem concentration of 0.3 % only one (1) failure test has been carried out. The measured static stiffness modulus, before breaking , was 2150 MPa, the tensile stress at the bottom of the beam was 1.88 MPa and the observed strain at failure was 875µm/m.**

   At ImmoCem concentration of 3 % three (3) failure tests were carried out. The measured static stiffness modulus, before breaking was from 2600 to 2950 MPa, the observed tensile stress at the bottom of the beam was 2.45 to 2.65 MPa and the observed strain at failure was 835 to 1000 µm/m.

   These are appropriate values for specimens before failure.

   The most important observation is the strain at failure which is very large compared to other cement- bound materials (cement concrete 150 to 200 µm/m, sand cement 125 µm/m). This offers unique possibilities for the use of ImmoCem in construction where large deformations as a result of high loads and/or a weak sticky underground are expected

2. **Both materials tested had initial dynamic stiffness modulus of 4000 MPa to 5000 MPa**

3. **The material can clearly be characterised as a flexible cement-bounded material:**
   a. **Below a certain tension level (proportion of applied tensile stress and tensile bending strength) the dynamic stiffness modulus remains constant and no fatigue damage occurs**
   b. **The dynamic stiffness modulus gradually decreases whereupon a rather brittle crack appears when the stiffness modulus shows a decreased tension level up to 60% à 70% of the initial value (just like for bituminous bound materials).**

4. **The results suggest that samples with 3,0% ImmoCem have somewhat better fatigue performance (in the sense that at the same initial tensile strain the number of load cycles before failure is larger) than 0.3% ImmoCem samples. More conclusive statements than this are not possible due to a limited number of tests carried out.**

5. **By far the most important conclusion is that behaviour of both materials tested, in spite of nearly constant density, was highly variable due to non homogenous material structure (presence of local bits of plastic, glass, foam polystyrene, etc.)**

   This seems to be particularly in the case of results for the fatigue tests on the ImmoCem 35/0,3 test beams 4 and 3 and the ImmoCem 35/3,0 test beams 1 and 4. Moreover in the ImmoCem 35/3,0 test beams hairline cracks were observed. The large variation in behaviour suggests a need for the use of relatively large safety factor in design with regards to the average fatigue behaviour.

6. **From two tests carried out with 2-point load cell on silt sand mixture (50/50) stabilized with cement and ImmoCem it can be concluded that the tensile bending strength of 2.5 to 2.75 MPa can be expected and that the breaking strain at failure of 750 à 875 µm/m can be achieved.**
   This corresponds to the stiffness modulus at failure of 2900 to 3700 MPa.

As limited as this research is, the results show that the ImmoCem material has potentially a wide range of applications in construction.

The challenge of obtaining and maintaining large strain at failure is to limit the variation in the strength while maintaining the increased average strength.

Depending on the intended field applications that either the fatigue or the tensile bending strength and/or the compressive strength can be most relevant.

Whilst the number of tests carried out is too small to stipulate a reliable average fatigue strength. It should be noted that large profits can be obtained by limiting the variation in material behaviour (heterogeneous sludge / sand).

A more homogeneous material would meet this requirement.