Large-Scale Bending Tests on Soil Mix Elements

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ABSTRACT: Since several decennia, the deep mixing method has been used to improve the strength and deformation characteristics of soft soils. A more recent trend is the use of this technique for the construction of soil mix walls designed as soil and water retaining structures. Within the framework of the BBRI Soil Mix project (2009-2013), seventeen large-scale bending tests have been performed on excavated soil mix elements previously executed in real construction sites. The purpose of this study was to question the contribution of the soil mix material to the bending resistance of the soil mix walls, up to now designed only on the basis of the steel (H- or I-) beam resistance. Various soil conditions and execution processes were considered in the course of this study. The present paper discusses the test results in terms of deflection, bending moment, steel-soil mix adherence and stresses in the steel reinforcement. The "real-scale" bending stiffness of the reinforced soil mix walls is then computed by back analysis. The measurement of the stresses in the steel (HEA or IPE) beams shows an efficient interaction between the soil mix material and the steel reinforcement: the yield strength was reached in the steel beam at bending moments 20 to 70 % higher than without any contribution of the soil mix.

INTRODUCTION

Originally, the deep mixing method has been developed for ground improvement applications in soft clays or organic soils. In recent years, this technique has increasingly been applied in Belgium and in other countries for the realization of soil and water retaining structures. With the deep mixing method, the ground is mechanically mixed in place while a binder, often based on cement, is injected. Columns or panels can be executed and placed next to each other, in a secant way.

By overlapping the different elements, a continuous soil mix wall is realized. Steel H or I-beams are then inserted into the fresh soil mix material to resist the shear forces and the bending moments that occur during excavation of the building pit. The main principle is that the soil mix material is designed to distribute the earth and water pressures between the steel wide flange H-beams (or I-beams). Hence, the soil mix material ensures the role of the arching effect. Until now, the designers considered that the bending moments were fully supported by the steel beams as a result of the lack of knowledge on the real contribution of the soil mix material to the bending resistance of the soil mix wall. In order to investigate this question, seventeen large-scale bending tests have been performed on "real-scale" reinforced soil mix elements (columns or panels) excavated from seven Belgian construction sites, with various soil conditions and for different execution processes (CVR C-mix®, TSM and CSM).

This experimental campaign is a part of the BBRI Soil Mix project (2009-2013), initiated in 2009 by the Belgian Building Research Institute (BBRI) in collaboration with the KU Leuven and the Belgian Association of Foundation Contractors (ABEF), the Belgian branch of the EFFC. Within this research project, deep soil mix material, from thirty-eight Belgian construction sites with various soil conditions and for different execution processes, has been tested. An overview of the results of the BBRI Soil Mix project (2009-2013) was published at the occasion of the ISSMGE TC211 International Symposium on Ground Improvement IS-GI 2012 (see Denies et al., 2012a).

The present paper discusses the results of the seventeen large-scale bending tests. Ranges of values are presented for the deflection, the bending moments, the steel-soil mix adherence and the stresses in the steel reinforcement. "Real-scale" bending stiffness is deduced from a back analysis as a function of these stresses. Suggestions are finally made to consider the results of these large-scale tests in standards and engineering codes.

EXECUTION AND PREPARATION OF THE SOIL MIX ELEMENTS

Firstly, the steel (HEA or IPE) beams were instrumented in the laboratory facilities of BBRI with an optical fiber installed on the two opposite flanges of the steel beams (see Fig. 1). The optical fibers (FBG/DTG technology) were used as non-reusable instrumentation systems for the measurement of the deformations along the two flanges of the steel beam during the bending test. Afterwards, directly after the execution *in-situ* of the soil mix elements (see Fig. 2), the instrumented steel beams were introduced into the fresh soil mix material, as illustrated in Fig. 3. After a few days of hardening, the soil mix panels were excavated (see Fig. 4) and transported to the laboratory facilities of BBRI, such as illustrated in Fig. 5.

Similar operations were also conducted on soil mix walls made of soil-cement columns. Fig. 6 illustrates the CSM panels and the soil-cement columns as delivered to the laboratory facilities of BBRI. Before testing, the CSM panels were then cut and half-CSM panels were transported in the laboratory for the realization of the bending tests. The soil-cement columns were individually tested after cutting. For soil-cement columns, tests were conducted on individual soil-cement column reinforced either with a steel beam or with a reinforcement cage.

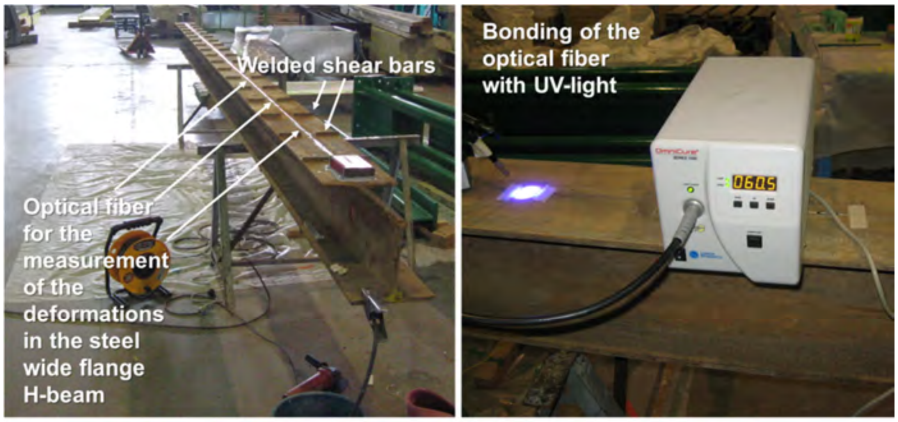

Fig. 1. Bonding of the optical fibers on the two opposite flanges of a steel wide flange H-beam (type HEA) in the laboratory facilities of BBRI

Fig. 2. Execution of a soil mix panel (type CSM) on the construction site of Aalst (Belgium)

Fig. 3. Installation of the instrumented steel wide flange H-beams in the fresh soil mix panel just after execution on the construction site of Aalst (Belgium)

Fig. 4. Excavation of the soil mix panels on the construction site of Aalst (Belgium)

Fig. 5. Arrival of the soil mix panels at the laboratory facilities of BBRI

Fig. 6. CSM panels and soil-cement columns before cutting and testing

For each construction site, the remaining soil mix material was used for the realization of large-scale UCS tests performed at KU Leuven (see Vervoort et al., 2012 for the details of the test procedures and Denies et al., 2014 for the summary of the test results) and for the mechanical characterization on typical core samples.

EXPERIMENTAL SETUP OF THE LARGE-SCALE BENDING TESTS

The large-scale soil mix elements (half-CSM panels and full-length columns) were subjected to 3- or 4-point bending tests, as illustrated in Fig. 7.

Fig. 8 presents the monitoring devices used within the framework of the large-scale bending tests. The central deflection δ (mid-length zone: under the application of the force) was continuously measured (sampling of 0.1 Hz) with the help of Linear Vertical Displacement Transducers (LVDT) installed on both sides of the soil mix element. The measurement of this deflection was always corrected taking into account the vertical displacement at the support beams measured with four LVDT's. In addition, the sliding between the steel (HEA or IPE) beam and the soil mix material was monitored during the test with a LVDT. The deformations were measured by means of the optical fibers previously installed on both flanges of the steel beam (10 measurement points for the inferior flange and 10 measurement points for the superior flange of the steel beam). The force applied in the center of the soil mix element with a hydraulic jack was measured by means of a load cell.

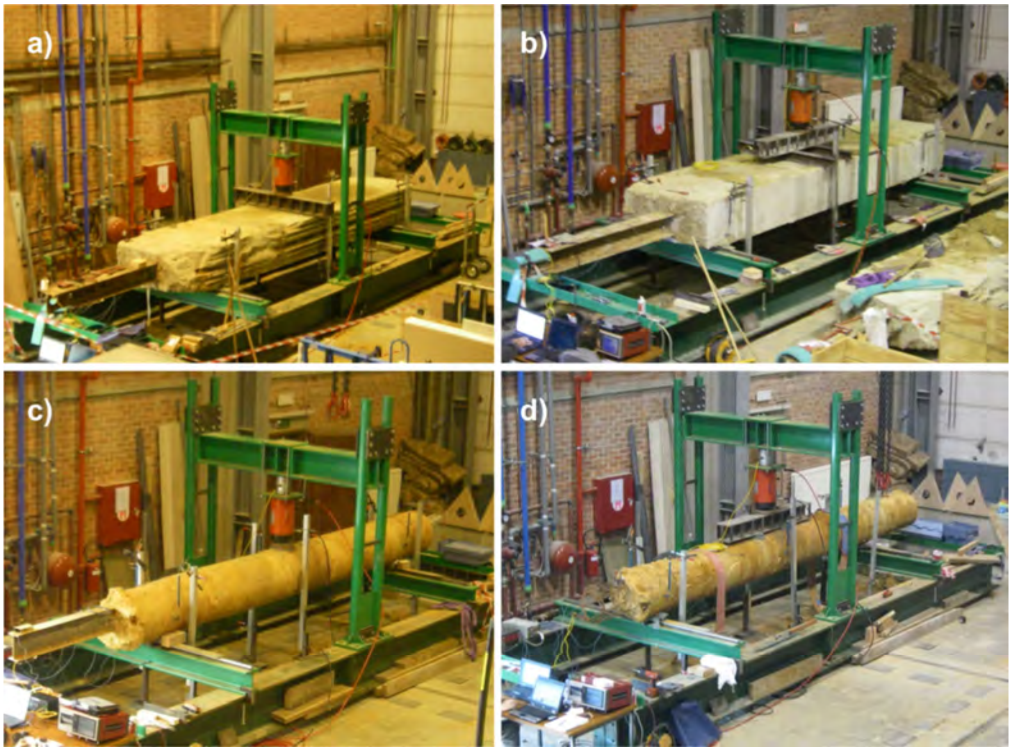

Fig. 7. Examples of large-scale bending test configurations such as used within the framework of the BBRI Soil Mix project (2009-2013)
a) and b) respectively 3-point and 4-point bending tests on half-CSM panels reinforced with a steel beam, c) 3-point bending test on a soil-cement column reinforced with a steel beam and d) 4-point bending test on a soil-cement column with a reinforcement cage

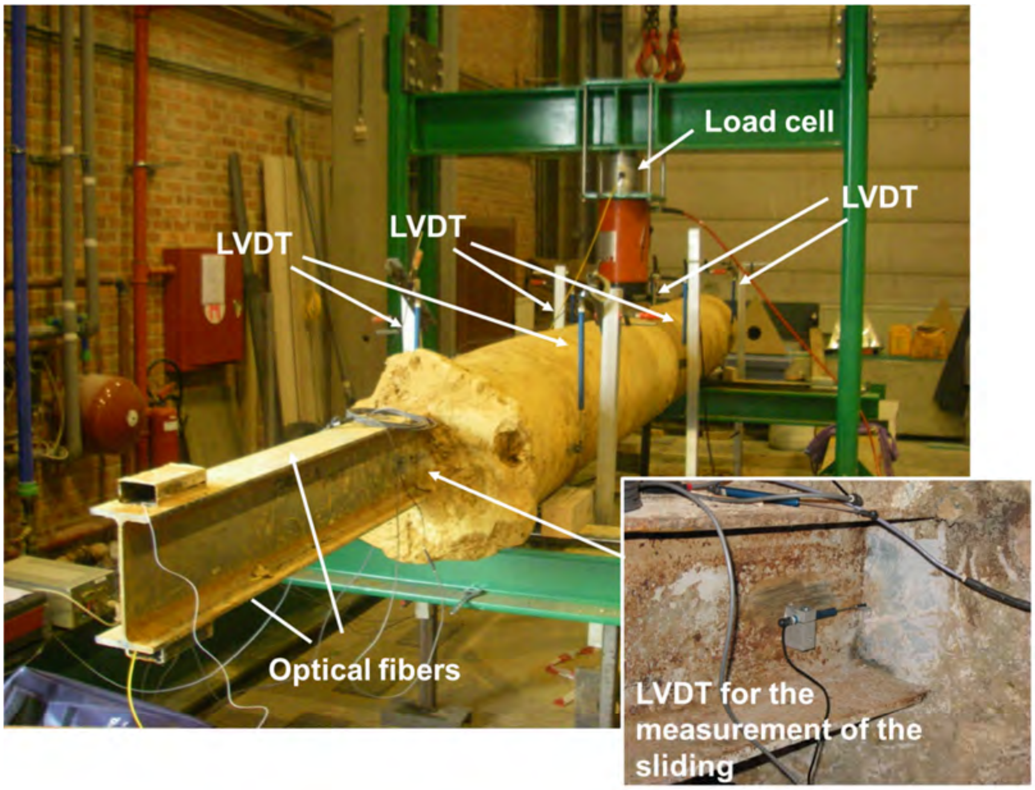

Fig. 8. Measurement devices used for the continuous monitoring of the soil mix element during the large-scale bending test

For each large-scale bending test, the static loading force was increased in steps (constant steps of 5 minutes) until failure of the soil mix element.

PURPOSES OF THE LARGE-SCALE BENDING TESTS

In Denies et al. (2014), the authors present in detail the results of a 3-point large-scale bending test applied on half a CSM panel reinforced with a steel wide flange H-beam (type HEA). The contribution of the soil mix material to the bending resistance was studied considering:

- the measurement of the deflection in function of the applied flexural moment,
- the assessment of the “real-scale” stiffness of the soil mix element,
- the analysis of the deformations and the stresses in the steel wide flange H-beam.

For each type of analysis, the observed behavior of the soil mix element was compared with the behavior of the steel wide flange H-beam only.

The purpose of the present paper is to compare the results of the complete set of the seventeen large-scale bending tests according to the aforementioned analysis (moment-deflection relationships, determination of the “real-scale” stiffness and analysis of the deformations).

RESULTS OF THE LARGE-SCALE BENDING TESTS

Table 1 gives a summary of the configuration of the seventeen large-scale bending tests performed in the laboratory facilities of BBRI. Tables 2 and 3 complete this information respectively giving the dimensions of the test sections and the mechanical properties of the soil mix material.

The first way to study the interaction between the soil mix material and the steel reinforcement is to analyze the relationships between the measured central deflection δ and the applied flexural moment M. Fig. 9 summarizes these relationships for thirteen large-scale bending tests (only the soil mix elements reinforced with a steel beam). As the tests were conducted on soil mix elements with several types of steel beams, all results are expressed in function of both ratios δ/δ_{el} and M/M_{el}. δ_{el} can be defined as the theoretical deflection of the steel beam only (so totally neglecting the presence of the soil mix material) under the application of a flexural moment M_{el} that leads to yield in the steel beam. The contribution of the soil mix material to the bending resistance can be quantified considering these two ratios and the value of the maximal flexural moment reached during the test and called M_{max}. Table 4 presents the values of both ratios for these thirteen large-scale bending tests. For the four large-scale bending tests performed on soil mix elements reinforced with cages, only the maximal flexural moment reached during the test is given.

Table 1. Summary of the large-scale bending tests performed by BBRI

Id.	Site	System and type of reinforcement	Type of soil	Configuration
1	Heverlee	CSM contractor 1 with HEA 240 (S235)	Tertiary sand	4 points
2	Heverlee	CSM contractor 1 with HEA 240 (S235)	Tertiary sand	3 points
3	Aalst	CSM contractor 2 with HEA 240 (S235)	Sandy loam	4 points
4	Aalst	CSM contractor 2 with HEA 240 (S235)	Sandy loam	3 points
5	Aalst	CSM contractor 2 with HEA 240 (S235) with reinforcement of the steel H-beam†	Sandy loam	4 points
6	Aalst	CSM contractor 2 with HEA 240 (S235) with reinforcement of the steel H-beam†	Sandy loam	4 points
7	Leuven	Column contractor 1 with IPE 240 (S235)	Sand with local stones	4 points
8	Leuven	Column contractor 1 with IPE 240 (S235)	Sand with local stones	3 points
9	Leuven	Column contractor 1 with reinforcement cage (6ϕ14 mm)	Sand with local stones	4 points
10	Leuven	Column contractor 1 with reinforcement cage (6ϕ14 mm)	Sand with local stones	3 points
11	Blankenberge	Column contractor 2 with IPE 180	Dune sand	4 points
12	Antwerpen	Column contractor 2 with IPE 270	Remolded soil	3 points
13	Antwerpen	Column contractor 2 with reinforcement cage	Remolded soil	3 points
14	Antwerpen	Column contractor 2 with reinforcement cage	Remolded soil	3 points
15	Knokke	Column contractor 2 with IPE 270	Peaty clay	3 points
16	Limelette	Column contractor 2 with IPE 220	Loam	3 points
17	Limelette	Column contractor 2 with IPE 220	Loam	3 points

†for this bending test, the steel wide flange H-beam was reinforced with welded shear bars, as illustrated in Fig. 1

Table 2. Dimensions of the test sections for the BBRI large-scale bending tests

Id.	**Section**	**A_{Steel}[†](cm²)**	**A_{SM}[‡](cm²)**
1	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
2	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
3	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
4	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
5	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
6	Rectangular: 60 cm x 120 cm (Half-CSM panel)	76.8 (HEA 240)	7123
7	Circular: 55 cm diameter (Soil-cement column)	39.1 (IPE 240)	2337
8	Circular: 55 cm diameter (Soil-cement column)	39.1 (IPE 240)	2337
9	Circular: 55 cm diameter (Soil-cement column)	9.2 (6ϕ14 mm)	2367
10	Circular: 55 cm diameter (Soil-cement column)	9.2 (6ϕ14 mm)	2367
11	Circular: 45 cm diameter (Soil-cement column)	23.9 (IPE 180)	1567
12	Circular: 67 cm diameter (Soil-cement column)	45.9 (IPE 270)	3480
13	Circular: 68 cm diameter (Soil-cement column)	-	3632
14	Circular: 65 cm diameter (Soil-cement column)	-	3370
15	Circular: 63 cm diameter (Soil-cement column)	45.9 (IPE 270)	3071
16	Circular: 65 cm diameter (Soil-cement column)	33.4 (IPE 220)	3285
17	Circular: 64 cm diameter (Soil-cement column)	33.4 (IPE 220)	3184

[†] *A_{Steel} is the area of the steel beam or the cumulated area of the reinforcing bars for the cages*
[‡] *A_{SM} is the area of the soil mix section excluding the area of the steel reinforcement*

Table 3. Mechanical properties of the soil mix material for each tested element

Id.	**Average UCS value**			**Average modulus of elasticity E[†]**		
	UCS (MPa)	**Number of tests**	**Core sample dimensions**	**E (GPa)**	**Number of tests**	**Core sample dimensions**
1 and 2[‡]	6.05	30	D*=94mm H*=94mm	7.04	4	D=94mm H=190mm
3, 4, 5 and 6[‡]	7.31	31	D=H=105mm	8.40	4	D=105mm H=210mm
7, 8, 9 and 10[‡]	10.02	67	D=H=114mm	6.37	4	D=114mm H=228mm
11	21.42	10	D=100mm H=95mm	12.90	5	D=95mm H=200mm
12	8.15	13	D=H=95mm	6.68	2	D=95mm H=190mm
13	15.63	12	D=H=95mm	13.74	2	D=95mm H=190mm
14	10.37	4	D=H=95mm	-	-	-
15	4.62	21	D=H=94mm	3.52	2	D=93mm H=200mm
16	10.73	11	D=H=93mm	9.85	2	D=93mm H=197mm
17	9.68	11	D=H=93mm	4.40	1	D=93mm H=194mm

[†] E is determined in a tangent way varying the applied load between 10% and 30% of the estimated UCS. The sample deformations are measured along three axes using DEMEC mechanical strain gauges.

[‡] For the three construction sites of Heverlee, Aalst and Leuven (id. 1 to 10), large scale Unconfined Compressive Strength (UCS) tests were also conducted on rectangular blocks with approximately a square section, with a width corresponding to the width of the *in-situ* soil mix wall (about half a meter) and with a height approximately twice the width. The results of these large-scale UCS tests are presented in Denies et al. (2014).

*D and H are respectively the diameter and the height of the core sample.

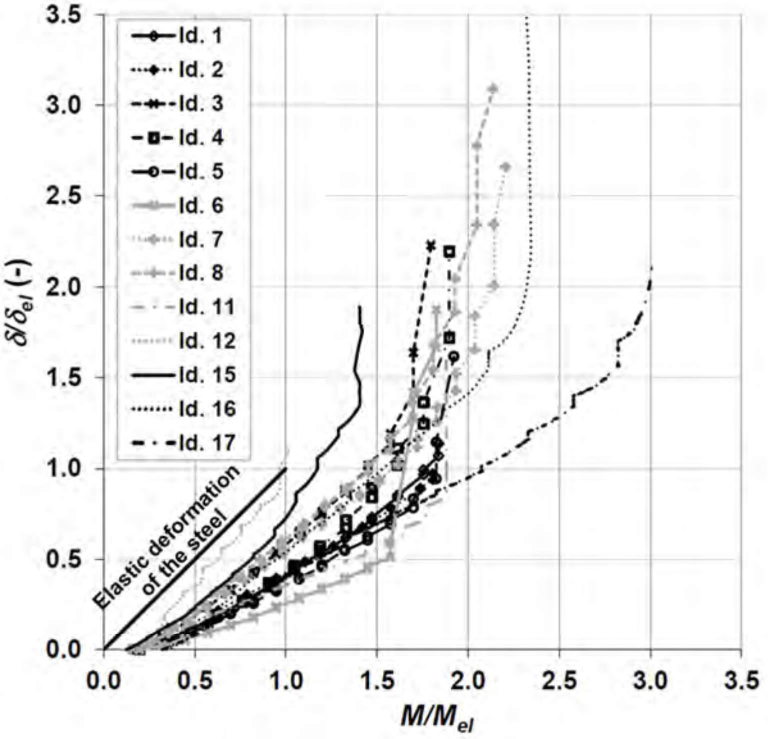

Fig. 9. Evolution of the central deflection in function of the applied flexural moment for the large-scale bending tests performed on soil mix elements reinforced with a steel beam

Table 4. Structural behavior of the soil mix elements: typical ratios and values

Id.	M_{max} (kNm)	M_{max}/M_{el} (-)	δ/δ_{el} once $M=M_{el}$	$EI_{steel\ beam}$ (10^3 kNm^2)	EI_{100MPa} (10^3 kNm^2)	EI_{180MPa} (10^3 kNm^2)	M/M_{el} once $\sigma=\sigma_{el}$
1	326	2.05	0.40	16.3	40	36	1.47
2	376	2.36	0.44	16.3	39	36	1.57
3	286	1.80	0.60	16.3	30	27	1.19
4	303	1.91	0.40	16.3	39	32	1.40
5	306	1.92	0.36	16.3	47	42	1.47
6	290	1.82	0.26	16.3	59	30	1.69
7	168	2.21	0.58	8.17	15	14.5	1.32
8	162	2.13	0.64	8.17	13.5	13	1.27
9	133	-	-	-	18.5	13.5	-
10	95	-	-	-	13	8	-
11	65	1.88	0.36	2.76	-	-	No stress measurement
12	103	1.02	1.06	12.16	-	-	No stress measurement
13	147	-	-	-	-	-	-
14	90	-	-	-	-	-	-
15	143	1.42	0.72	12.16	-	-	No stress measurement
16	139	2.34	0.54	5.82	10.5	10	1.38
17	178	3.01	0.40	5.82	14.5	15	1.59

As seen in Fig. 9, except for the test identifications 12 and 15, the ratios δ/δ_{el} (once $M/M_{el} = 1$) range between 0.26 and 0.64 (-), so the deflection is at least 36 % lower due to the presence of the soil mix material. Moreover, the maximal moments applied during the tests (and defined as the moment at failure), M_{max}, seem always significantly higher than the flexural moment corresponding to the yield strength of the steel beam only. The values of M_{max}/M_{el} range between 1.8 and 3. These results clearly demonstrate the contribution of the soil mix material to the bending resistance of the soil mix wall. Two bending tests do not fit within these general ranges.

The bending test *id. 15* actually refers to a soil-cement column installed in peaty clay. In this particular case, the relatively low level of contribution of the soil mix material to the bending resistance (δ/δ_{el} once $M/M_{el} = 1$ equals 0.72 and M_{max}/M_{el} equals 1.42) can be related to the high percentage of unmixed soft soil inclusion encountered in the soil mix material: 35 %. The determination of this percentage was based on a visual analysis presented in Denies et al. (2012b).

The bending test *id. 12* refers to a test performed on a soil-cement column reinforced with a steel (IPE) beam positioned, for the purpose of the investigation, with a large horizontal eccentricity, such as illustrated in Fig. 10. It is worthwhile to note that in spite of this large eccentricity, the failure of the column is only observed at the yield strength of the steel beam indicating that the flexural load is still delivered to the steel beam during the test.

Considering the curves in Fig. 9, it can be noted that there is an initial applied flexural moment different from zero. This latter can be related to the flexural moment due to the own weight of the soil mix element put on the two support beams. For all tests, the measurement of the deflection was started once the force was applied to the soil mix element. Initial deflection due to the own weight of the soil mix element was not considered in the present analysis.

One of the purposes of this experimental campaign was the assessment of the “real-scale” stiffness of the soil mix elements. The latter, defined as EI_{real}, can be computed by back analysis for the 3- and 4-point bending tests:

$$EI_{real}{}^{3-point} = \frac{(M - M_{weight})L^2}{12\delta} \text{ and } EI_{real}{}^{4-point} = \frac{(M - M_{weight})(2L^2 + 2La - a^2)}{24\delta} \qquad (1)$$

where L is the distance between the two support beams and a the distance between the two loading beams for the 4-point bending test configuration (see Fig. 7b).

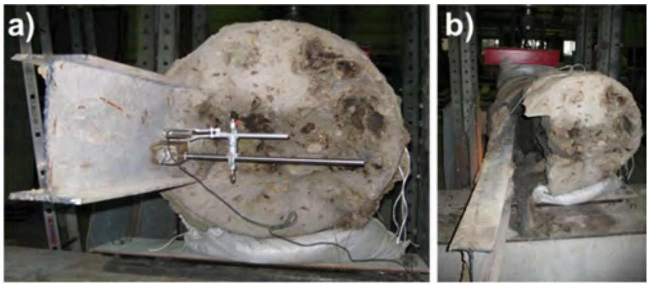

Fig. 10. Large-scale bending test *id. 12:* Eccentric positioning of the steel beam, a) before and b) after testing

Fig. 11 presents the evolution of the "real-scale" stiffness in function of the applied flexural moment for four half-CSM panels subjected to large-scale bending tests. As a result, there is an obvious contribution of the soil mix material to the stiffness of the soil mix elements. In Fig. 11, the measured "real-scale" stiffness is compared to 1. the theoretical stiffness of the steel wide flange H-beam only, 2. the theoretical stiffness of the uncracked soil mix material only and 3. the total theoretical stiffness of the uncracked reinforced half-CSM panels (the sum of the two previous values).

As observed in Fig. 11, during the test, the "real-scale" stiffness decreases with the increase of the flexural moment as a consequence of the progressive cracking of the soil mix material in the tensile zone. There is a progressive displacement of the neutral axis in the section during the test. Finally, the value of the "real-scale" stiffness reaches the stiffness of the steel wide flange H-beam only, at failure.

In the range of flexural moments supported by the soil mix wall, the "real-scale" stiffness is larger than the stiffness of the steel reinforcement only. That observation should be taken into account in the design models to obtain an accurate assessment of the bending moments in the soil mix walls. For the sake of information, two ranges of "real-scale" stiffness are given in Table 4. These ranges correspond to values of stresses in the steel beam respectively of 100 MPa and 180 MPa.

Finally, it can be noted that the different values of the "real-scale" stiffness seem to have already decreased at the beginning of the test with regard to the total theoretical stiffness of the reinforced half-CSM panels. This could be related to the flexural moment due to the own weight of the panel put on the two support beams, called M_{weight}. Indeed, in most of the cases, M_{weight} is really close to the flexural moment corresponding to the onset of the cracks in the soil mix material. This flexural moment is met when the (relatively low) tensile strength of the soil mix material is reached. Moreover it was not possible to verify if internal cracking initially occurred during excavation, removal, handling and transportation of the soil mix elements.

During the experimental campaign, a parametric study was performed to determine the factors governing the "real-scale" stiffness of the soil mix elements. Apart from the homogeneity of the soil mix material (as previously discussed for the bending test *id. 15*), the influence of the positioning of the steel reinforcement with regard to the section of the soil mix element was found to be the most relevant parameter. The eccentricity of the steel beam can be, for example, expressed with a dimensionless parameter, ν, such as defined in the inset of Fig. 11. As observed in this figure, there is a clear influence of the positioning of the steel reinforcement on the "real-scale" stiffness of the soil mix element. The more the steel beam tends to be situated in the tensile zone (increasing ν), the higher is the resulting "real-scale" stiffness.

In Denies et al. (2014), the question of the sliding between the steel beam and the soil mix material was highlighted. For the purpose of investigating the influence of the steel-soil mix adherence on the flexural behavior of the soil mix element, two types of steel wide flange H-beam were used for the four large-scale bending tests illustrated in Fig. 11. Two tests were performed with typical steel H-beams (HEA 240) and the two others with steel H-beams (HEA 240) with shear bars welded on the flanges of the steel H-beams (as illustrated on the left side of Fig. 1). The progressive sliding occurring during these four bending tests is given in Fig. 12 in function of the applied flexural moment.

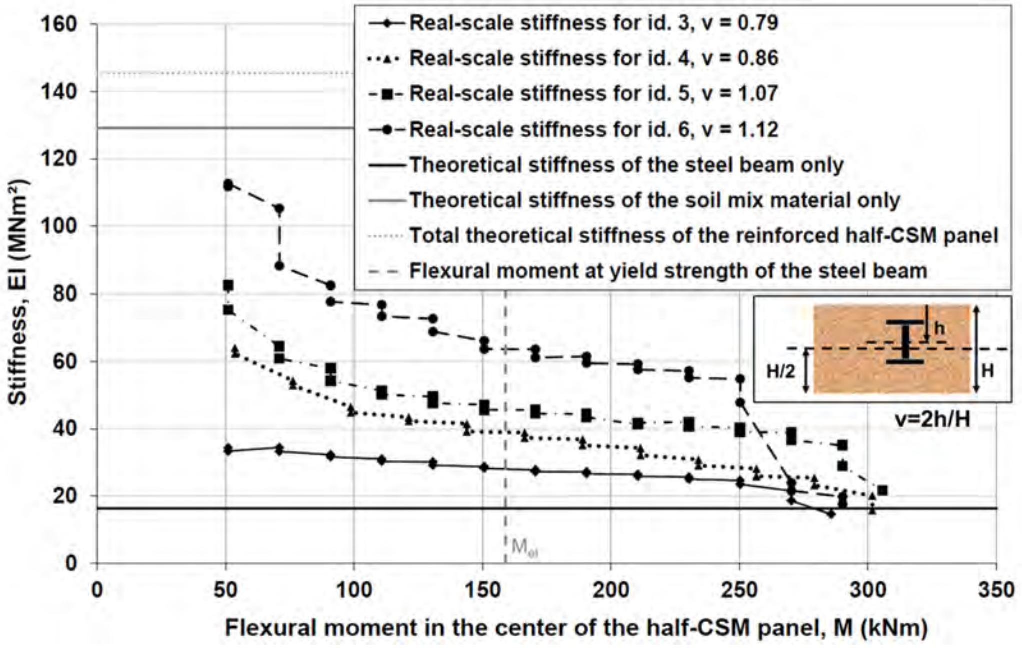

Fig. 11. Variation of the "real-scale" stiffness of half-CSM panels in function of the applied flexural moment; Inset: definition of the dimensionless parameter, v

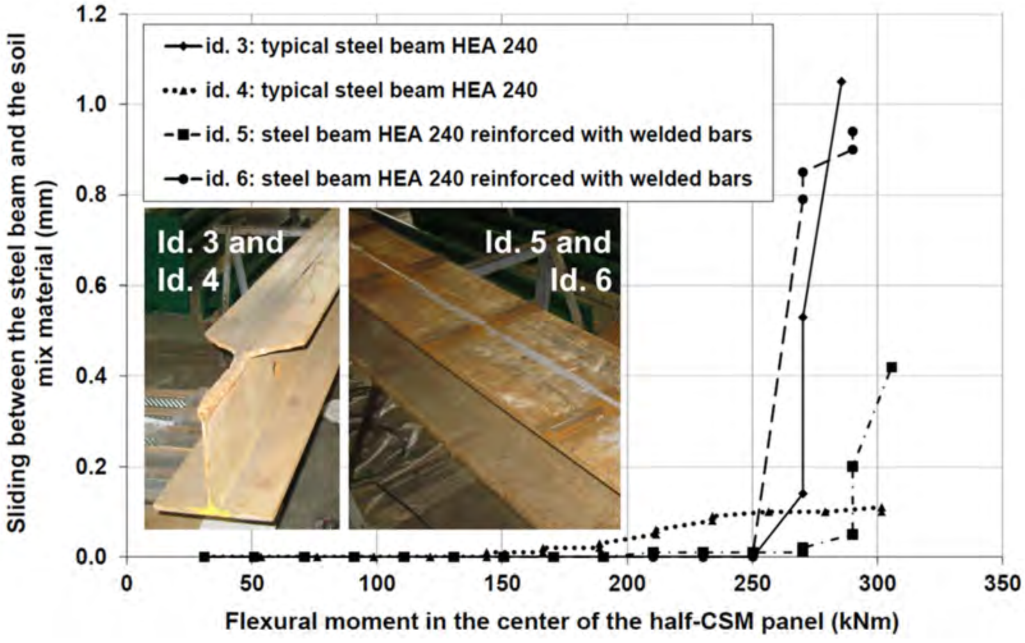

Fig. 12. Evolution of the sliding between the steel beam and the soil mix material during the large-scale bending test

From these tests, it can be concluded that the presence of the shear bars, welded on the flanges of the steel beam, does not present a significant influence on the adherence between steel and soil mix and on the maximal flexural moment, M_{max}, reached during the test. Steel-soil mix adherence was previously tested with the help of *in-situ* pull-out tests (Denies et al., 2012a). For typical IPE steel beams, the peak extraction resistance was shown to vary between 0.7 to 1.5 MPa as a function of the UCS of the soil mix material.

Fig. 13 gives some illustrations of the soil mix elements after testing and after removal of the steel reinforcement with the help of a steel chisel. Some unmixed soft soil inclusions are still visible in Fig. 13a.

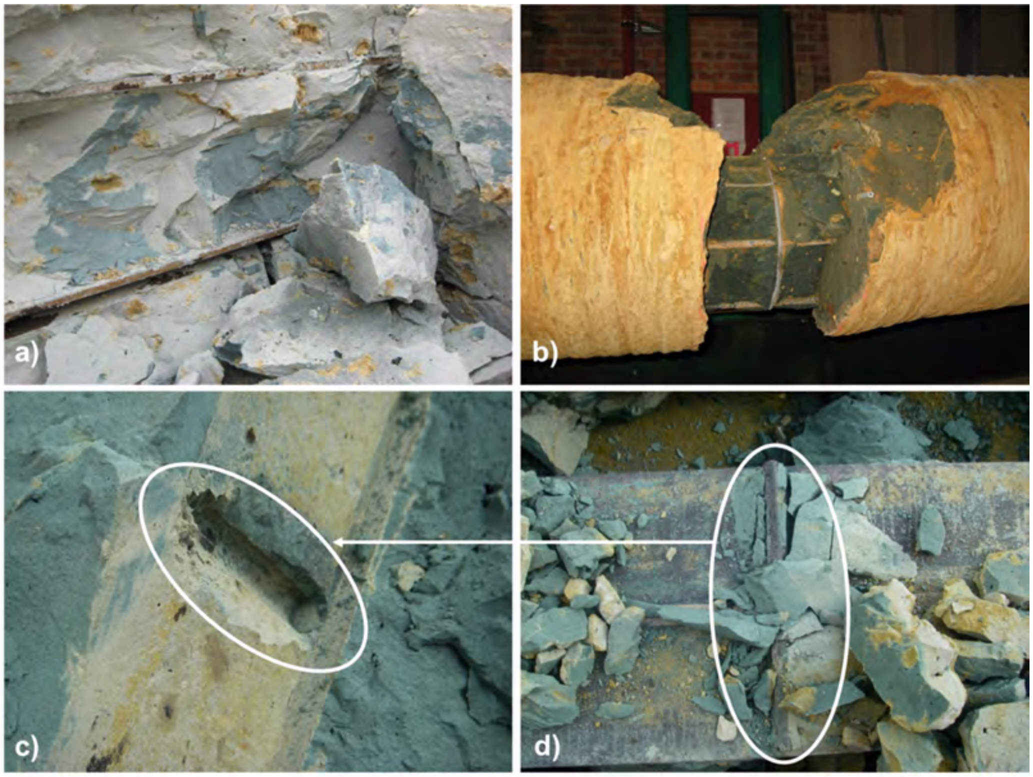

Fig. 13. Soil mix elements after testing and after removal of the steel reinforcement for the half-CSM panel *id. 3* (a), the soil-cement column *id. 9* (b) and the half-CSM panel *id. 6* (c and d)

The last stage of this experimental campaign is the analysis of the deformations occurring on both flanges of the steel beam during the test. Deformations were measured with the help of 10 measurement points on each flange of the steel beam. For the sake of illustration, the evolution of the deformations arising during the test *id 8* is presented in Fig. 14.

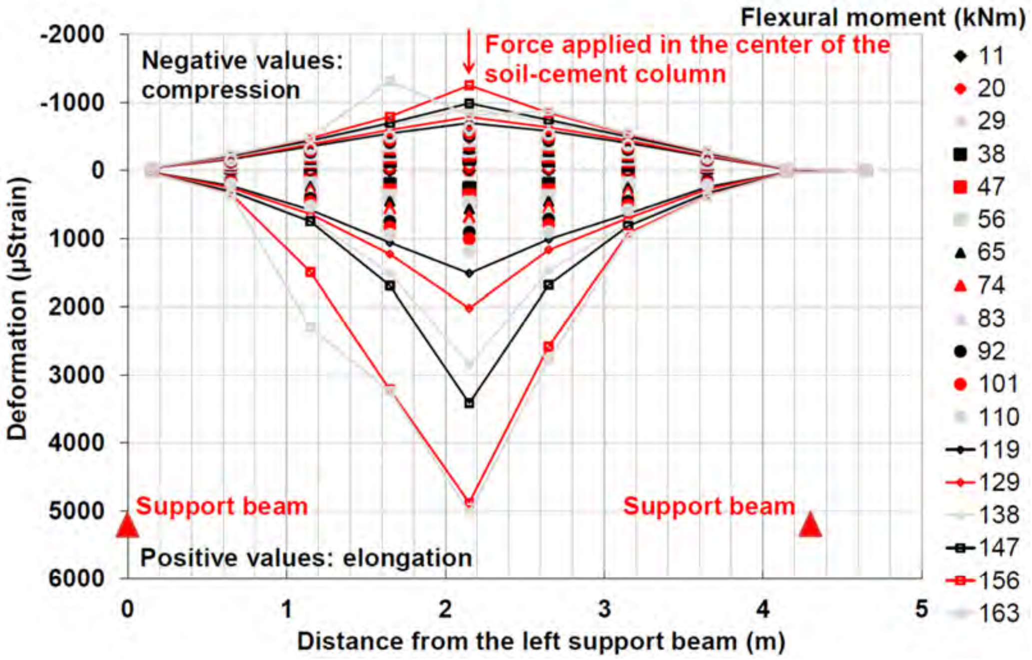

Fig. 14. Deformations along the steel beam during the bending test *id 8*

As observed for most of the tests, the asymmetrical development of the deformations during the test (on both flanges of the beam) can be related to the progressive cracking of the soil mix material in the tensile zone and to the positioning of the steel beam. As previously mentioned, there is a progressive displacement of the neutral axis in the section during the test.

The stresses along the steel beam are then computed on the basis of these deformations. Fig. 15 illustrates the evolution of the stresses in the center of the soil-cement column in function of the applied flexural moment for the large-scale bending test *id 8*. As observed in Fig. 15, the yield strength is reached in the steel beam ($\sigma = \sigma_{el}$) at a flexural bending moment which is 27 % higher than expected (according to the assumption that the bending resistance is only supported by the steel beam). This percentage is given for the other large-scale bending tests in Table 4. The measurement of the stresses along the steel beam demonstrates an efficient interaction between the soil mix material and the steel reinforcement: due to the soil mix material, the yield strength is reached in the steel beam ($\sigma = \sigma_{el}$) at bending moments which are 20 to 70 % higher than without any contribution.

It can be noted that the stresses, represented in Fig. 15, are computed on the basis of Hooke's law. As this latter is only valid in a limited range of deformation, there is an uncertainty on the values of the stresses computed at large deformations. Until the yield strength is reached in the steel beam, Hooke's law still remains valid and the conclusion for the contribution of the soil mix material to the bending resistance of the soil mix wall (input of 20 to 70 %) is therefore valid.

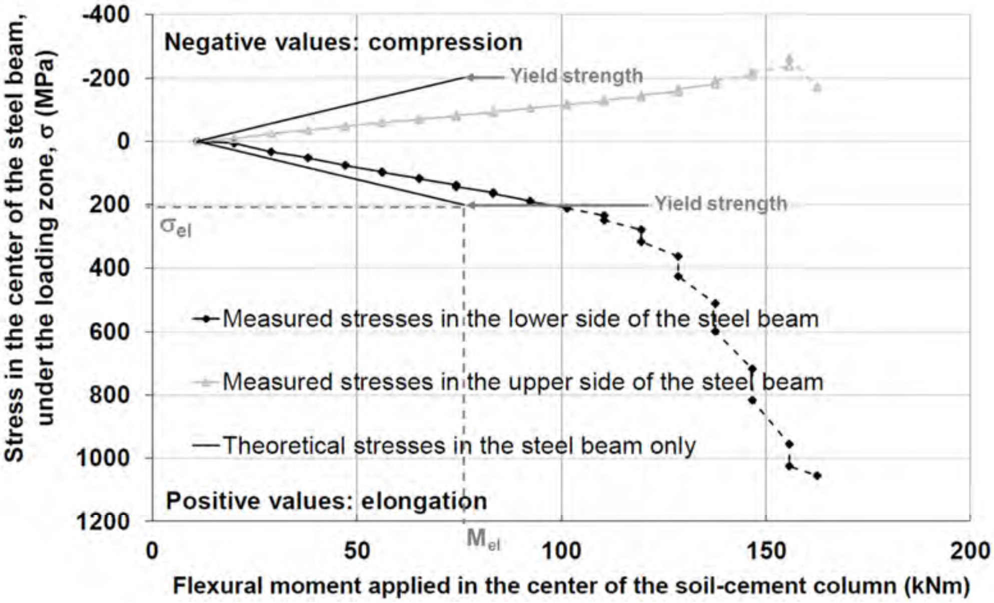

Fig. 15. Stresses along the steel beam during the large-scale bending test *id 8*

CONCLUSIONS

The present paper discusses the results of seventeen large-scale bending tests performed on “real-scale” soil mix elements. These soil mix elements were excavated from seven Belgian construction sites with various soil conditions (tertiary sand, dune sand, sand with local stones, loam, sandy loam, peaty clay and remolded soil). Seven soil-cement columns and ten half-CSM panels were tested in the laboratory facilities of BBRI. Soil-cement columns were either reinforced with steel beam or with cage.

For the soil mix elements reinforced with a steel beam, the analysis of the test results highlights the contribution of the soil mix material with an important gain with regard to the deflection and the stiffness of the soil mix element. The “real-scale” stiffness depends on the flexural bending moment applied to the soil mix element. It decreases with increasing flexural moment as a consequence of the progressive opening of the cracks in the soil mix material, as there is a progressive displacement of the neutral axis in the section during the test. In the range of the flexural bending moments supported by the soil mix wall, the “real-scale” stiffness is significantly larger than the stiffness of the steel reinforcement only. That observation should be taken into account in the design models especially to assess with accuracy the bending moments in the soil mix walls.

The maximal flexural moment applied during the test, M_{max}, is a factor 1.8 to 3 times higher than the flexural moment corresponding to the yield strength of the steel beam only.

The measurement of the stresses in the steel beams shows an efficient interaction between the soil mix material and the steel reinforcement: the yield strength was reached in the steel beam ($\sigma = \sigma_{el}$) at bending moments 20 to 70 % higher than without any contribution of the soil mix material.

Please note that due to the limited duration of each load step (5 minutes), creep was not considered in the present study.

In consequence of these experimental results, at least for temporary construction, a contribution of the soil mix material to the bending resistance could be considered in the design resulting in a certain reduction on the steel reinforcement. It is aimed to introduce this in the new design rules for soil mix walls that will be published jointly by the BBRI and the SBRCURnet in a handbook titled “Soil Mix Walls” (publication foreseen in 2015).

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