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Geomechanical characterization of an Italian complex formation with a block-in-matrix fabric

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Abstract. Melanges are chaotic and heterogeneous geological mixtures of strong rock blocks embedded in a weaker finer-grained matrix. These complex formations, often referred to as “bimrocks” (block-in-matrix rocks) and “bimsoils” (block-in-matrix soils), are characterized by a high spatial, dimensional and lithological variability. Such a variability, together with the presence of rock inclusions of different lithologies and dimensions, makes the collection of representative high-quality specimens for laboratory tests very challenging. As a consequence, the determination of the geomechanical properties of such geomaterials is extraordinarily problematic. In this paper a preliminary characterization of an Italian sedimentary chaotic melange is performed by means of several laboratory tests. In dry conditions it looks like a bimrock but it is very sensitive to water and will transform into a bimsoil if it comes into contact with water. Since conventional drilling methods could not be employed to collect the specimens, a manual coring had to be used. The irregular lumps obtained were then cut with a specially made cutting machine. Point load tests and uniaxial compression tests were performed on the melange specimens. Atterberg limits, grading curves and mineralogical analyses were further carried out on the matrix material, in order to characterize it. The paper comments on both the procedure of these tests and the results obtained.

1. Introduction

Bimrocks (block-in-matrix rocks) and bimsoils (block-in-matrix soils) are heterogeneous complex formations composed of competent rock blocks embedded in a matrix of fine and often sheared texture [1]. These geomaterials are characterized by a high spatial, lithological and dimensional variability. Such a variability, together with the presence of rock inclusions of different lithologies and dimensions, makes the collection of representative high-quality specimens for laboratory tests very challenging [2–7]. Moreover, these complex formations cannot be considered either as rocks or as soils, which means that neither standard rock nor soil mechanics testing equipment is generally adequate to characterize them [8]. As a consequence, the determination of the geomechanical properties of such geomaterials is extraordinary problematic.

When dealing with melanges, which are the most widespread and among the most abundant block-in-matrix formations, further complexity is generally added by the argillaceous matrix and its sensitivity to water. In particular, conventional drilling methods cannot be employed without damaging the geomaterial. Hence, a manual coring is generally necessary in order to collect representative specimens to be tested in the laboratory.

In this paper, a preliminary geomechanical characterization of an Italian melange was carried out to deepen the actual problems highlighted previously and provide a possible solution to meet future challenges. In particular, the efforts made for the collection and preparation of regular and intact specimens of this geomaterial are illustrated in detail. Point load tests (PLT) and uniaxial compression tests were performed on these melange specimens. Grading curves, Atterberg limits and mineralogical analyses were also carried out on the material under study, in order to characterize it. The paper comments on both the procedure of these tests and the results obtained.

2. The Italian complex formation

The Italian complex formation analysed in this paper is a sedimentary chaotic melange located in the Oltrepò Pavese region (Figure 1).

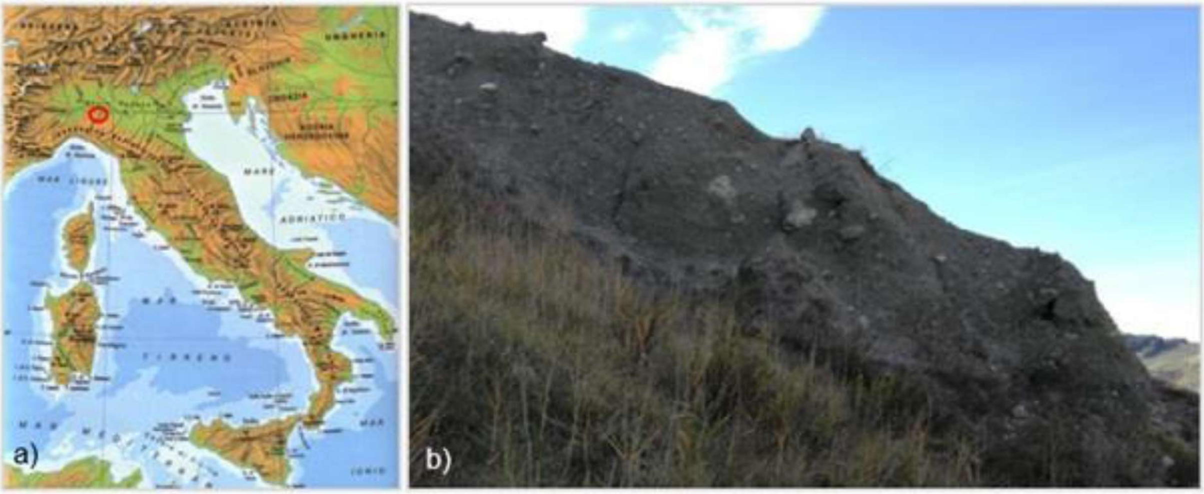

Figure 1. a) Location of the Oltrepò Pavese region (Pavia, Italy); b) an outcrop of the Oltrepò Pavese sedimentary melange.

The material under study, up to 180–200 m in thickness, is constituted by a compact clayey-marly matrix ($\gamma \approx 22$ kN/m^3) enclosing mainly calcareous rock blocks of different shapes and dimensions. As shown in Figure 2, the blocks are characterized by an inverse grading of the largest blocks above a basal shear zone, which is 5–10 cm thick [9]. In dry conditions it looks like a bimrock. However, it is very sensitive to water and will transform into a bimsoil if it comes into contact with water.

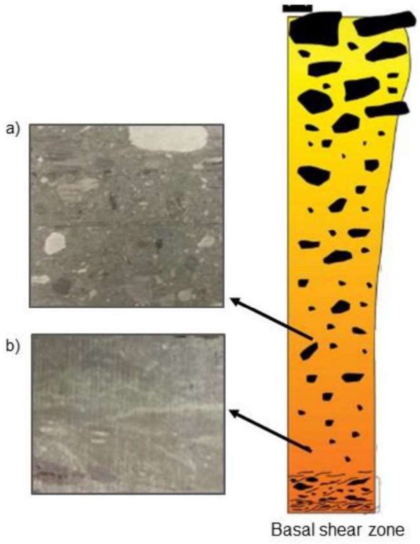

Figure 2. Conceptual stratigraphic column of a single melange strata, modified after [9]: a) heterogeneous melange with tabular blocks with dimensions gradually decreasing downwards; b) matrix-only melange located near the basal shear zone.

The weak nature of the marl and its sensitivity to water, as well as the presence of the stronger blocks, made the collection and preparation of regular and intact specimens extremely difficult and a time consuming operation. In fact, conventional drilling methods could not be employed to collect core samples without damaging the material. Hence, a manual coring had to be used [10].

Irregular samples (Figure 3a) were extracted with hammers, picks and chisels at different outcrop depths in order to obtain both heterogeneous and only-matrix melange samples. Since no standard technique (e.g. core drilling, oil circular saw or water circular saw) could be adopted to obtain regular specimens from the shapeless lumps, a specially made dry cutting machine was used to cut them (Figure 3). The cutting machine is a wood band saw with a sufficient cutting height and weight to avoid vibrations during the cutting operations. The supplied blade was replaced with a diamond blade (Figure 3b) specifically built for cutting the stronger rock inclusions without deforming the marly matrix. The band rotates at a constant speed while the specimen is pushed manually towards the rotating band saw by means of two boards (appositely constructed), in order to guarantee safety. An additional plastic element was also designed and printed to be connected to a vacuum cleaner for the dust containment (Figure 3c).

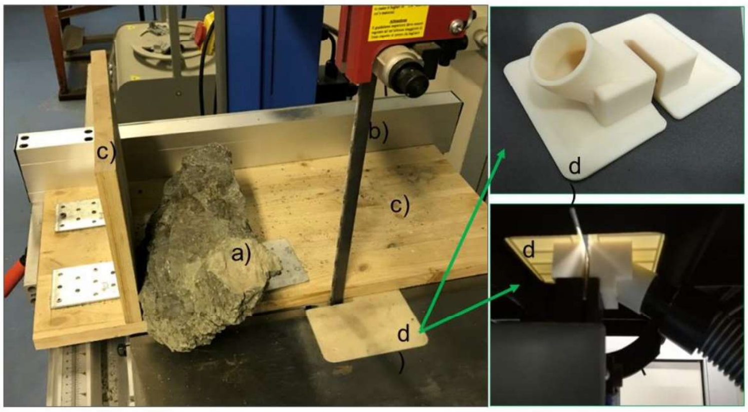

Figure 3. Diamond band saw. a) irregular lump; b) diamond blade; c) boards; d) plastic element for dust containment and connection between the vacuum cleaner hose and the plastic element

Point load tests and uniaxial compression tests were performed on this formation in the DIPLAB Geomechanics Laboratory (operating in the DISEG Department of Politecnico di Torino) for a preliminary estimation of its geomechanical behaviour. Moreover, Atterberg limits, grading curves and a mineralogical analysis were also carried out on the loose material, in order to characterize it.

3. Laboratory tests for the characterization of the loose material

3.1. Grading curves

In order to obtain the grading of the melange under study, a grading curve for both the matrix-only (i.e. melange sample collected close to the basal shear zone) and the heterogeneous block-in-matrix material was determined.

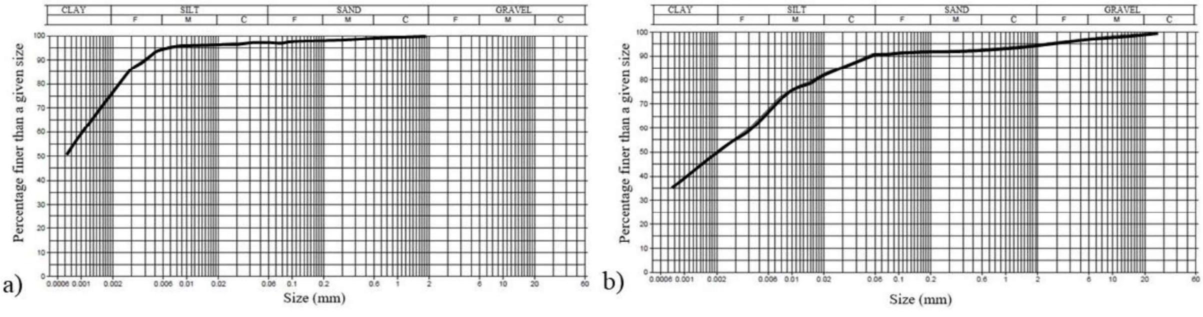

Figure 4. Grading curves of: a) the only-matrix melange; b) the heterogeneous melange.

As shown in Figure 4, the homogeneous material is a silty clay (77.3% of clay), while the heterogeneous one is a clay (50.3%) with 40.7% silt and 5.2% gravel.

3.2. Mineralogical analysis

In order to determine the mineralogy of the melange matrix of the Italian complex formation under study, the non-destructive X-ray diffraction (XRD) technique was used. The melange sample was treated and washed with distilled water. Then, the finest clay was ground and smeared on the surface of a glass slide, which was put into the X-ray diffractometer of the DIATI Department of Politecnico di Torino. Finally, a diffractometric spectrum was produced, providing the results reported in Table 1. The X-ray diffraction study indicates that the melange matrix is dominated by quartz and calcite.

Table 1. Scan data results.

Components	Content
Quartz	about 37%
Calcite	about 19%
Phengite	about 14%
Illite	about 12%
Dolomite	about 10%
Albite	about 8%

3.3. Atterberg limits

The Atterberg limits allow the determination of the water contents at which a material starts to flow like a liquid (W_L), ceases to be plastic and becomes brittle (W_P). These tests were determined for three melange samples, after the removal of particles which were larger than 425 µm (i.e. sieve ASTM 40).

In order to perform the Atterberg limits, distilled water was added and thoroughly mixed to each soil sample. A spatula was used to repeatedly knead the soil mixture, taking care to prevent the entrapment of air bubbles within the mixture [11]. The results obtained, reported in Table 2, indicate that the average W_L is 61.6, W_P is 24.5 and PI is 37.1. As a consequence, the matrix is an inorganic clay of high plasticity with a consistency index (CI) greater than 1.5. This corresponds to a solid state [12].

Table 2. Limits of consistency of the matrix melange.

Sample	Liquid limit (W_L)	Plastic limit (W_P)	Plasticity index (PI)	Water content (w)
1	61.2	24.5	36.7	3%
2	61.3	23.9	37.4	5%
3	62.2	25.1	37.1	5%

4. Laboratory tests on regular melange samples

In order to characterize the complex geomaterial under study, PLT and uniaxial compression tests were carried out on the melange specimens cut with the diamond band saw.

4.1. Point load tests

PLT are the most used tests when dealing with weak rocks [13,14], such as melanges. In fact, these tests can be easily conducted even on irregular specimens, avoiding technical difficulties such as sample preparation [15,16]. The relationship between the point load strength index (PLI), $Is_{(50)}$, and the uniaxial compressive strength, UCS, is expressed by a conversion factor, K. This parameter, according to Agustawijaya (2007), can be set equal to 14 for the weak rock under study.

All the heterogeneous specimens tested were previously regularized by means of the diamond band saw, as shown in Figure 5. The dimensions of the samples were 33 to 65 mm wide and 6 to 50 mm high. Since almost all the samples had some visible planes of weakness, the load was applied perpendicularly to the planes of anisotropy, in order to obtain the greatest strength values.

Figure 5. A melange specimen regularized by means of the diamond band saw for the PLT.

As shown in Table 3, different uniaxial compressive strength values were found for each sample, with an average value of 2.5 MPa and a standard deviation of 1.7. This variability can be ascribed to both local microfractures as well as to the presence of blocks of variable dimensions and positions within the specimens. However, since the blocks had limited sizes and constituted less than 10% of the total volume of each specimen, they should provide little geomechanical advantage according to previous findings from the literature [17–19].

Table 3. Results of the point load tests on the heterogeneous specimens.

Sample	D [mm]	W [mm]	D' [mm]	De^2 [m^2]	P [kN]	Is [kN/m^2]	De [mm]	F [-]	Is_{50} [kPa]	UCS [MPa]
1	16	35	16	0.0007	0.28	392.5	26.7	0.75	296.0	4.14
2	23	38	23	0.0011	0.50	449.1	33.4	0.83	374.4	5.24
3	30	33	31	0.0013	0.32	245.6	36.1	0.86	212.1	2.97
4	20	34	19	0.0008	0.40	486.1	28.7	0.78	378.5	5.30
5	20	33	19	0.0008	0.48	601.0	28.3	0.77	464.9	6.51
6	50	65	44	0.0036	0.10	27.5	60.4	1.09	29.9	0.42
7	50	50	50	0.0032	0.48	150.7	56.4	1.06	159.2	2.23
8	41	42	41	0.0022	0.30	136.8	46.8	0.97	132.8	1.86
9	36	36	38	0.0017	0.15	86.1	41.8	0.92	79.4	1.11
10	50	51	49	0.0032	0.23	72.2	56.4	1.06	76.3	1.07
11	31	35	37	0.0016	0.30	181.9	40.6	0.91	165.6	2.32
12	34	34	36	0.0016	0.27	173.2	39.5	0.90	155.7	2.18
13	35	36	40	0.0018	0.15	81.8	42.8	0.93	76.3	1.07
14	25	26	25	0.0008	0.18	217.4	28.8	0.78	169.5	2.37
15	36	40	34	0.0017	0.30	173.2	41.6	0.92	159.4	2.23
16	34	34	37	0.0016	0.10	62.4	40.0	0.90	56.5	0.79
17	37	44	40	0.0022	0.30	133.8	47.4	0.98	130.6	1.83
18	40	41	40	0.0021	0.20	95.7	45.7	0.96	91.9	1.29

4.2. Uniaxial compression tests

In order to evaluate and compare the strength of both the homogeneous and heterogeneous melanges, several uniaxial compression tests were performed on the cut specimens. However, it was not possible to obtain specimens with either a cylindrical shape or an H/D ratio of 2.5, since block detachments and local fracture developments occurred during the cutting operations in almost all cases. An example of a cut specimen is given in Figure 6.

Figure 6. A melange sample with a fracture developed during the cutting operations.

These drawbacks, requiring more cuts than expected, compromised the final geometry of the specimens, which were sometimes so damaged that they could not be used. In particular, only 5 samples, with a variable H/D ratio ranging from 1.38 to 1.75, could be obtained from more than 15 shapeless lumps. Due to these limitations, the results of the uniaxial compression tests, reported in Table 4, should be considered only as an indication of the strength of the melange. However, the UCS of the heterogeneous specimens are comparable to the average value obtained with the PLT (i.e. 2.5 MPa). Similarly to the PLT, the load was applied (as much as possible) perpendicularly to the planes of weakness, in order to achieve the greatest strength values.

The rock content of the specimens, less than 10% as reported in Table 4, was obtained by means of sieve analyses carried out after each test.

Table 4. Results of the uniaxial compression tests.

Sample	Description	Rock block proportion [%]	H/D	UCS [MPa]
1	Only-matrix	0	1.38	2.20
2	Only-matrix	0	1.74	0.98
3	Only-matrix	0	1.52	1.56
4	Heterogeneous	5.1	1.67	1.96
5	Heterogeneous	6.9	1.75	2.40

Moreover, a notable result concerning the failure surfaces of such geomaterials was observed during the tests. As shown in Figure 7, the failure surfaces of the homogeneous (i.e. only-matrix) and heterogeneous specimens were very different. In fact, in the heterogeneous specimens the failure surfaces developed tortuously around the blocks (i.e. within the matrix), as can be seen in Figure 7b. On the contrary, the matrix-only specimens were characterized by multiple fractures developing mainly horizontally (i.e. along foliation) and diagonally.

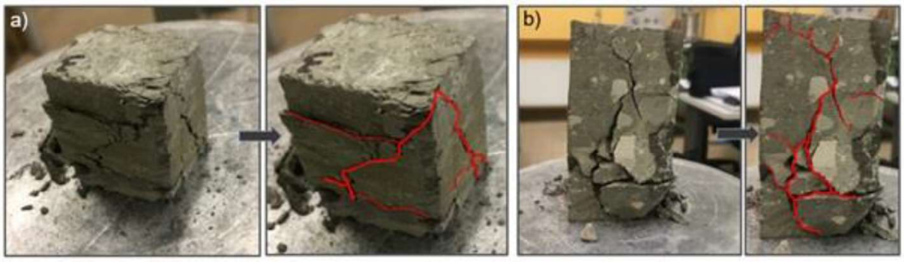

Figure 7. Failure surface after the uniaxial compression test: a) matrix-only melange specimen (sample 3); b) heterogeneous melange specimen (sample 4).

This result, which indicates that a different mechanical behaviour should be expected between homogeneous and heterogeneous geomaterials, confirmed previous findings from the literature [18,20–25], even for very low rock block proportions.

5. Conclusions

The melange under study is a complex formation composed of a generally slightly sheared clayey-marly matrix enclosing stronger rock blocks arranged in a chaotic fashion. The presence of the rock inclusions, as well as the weak nature of the marl (containing planes of weakness, especially in the case of the homogeneous material) and its sensitivity to water, made the collection and preparation of regular and intact specimens for laboratory tests a challenging task. A manual coring was necessary since no standard drilling could be used. In order to obtain both heterogeneous and matrix-only melanges, the samples were expressly taken at different outcrop depths. In fact, the geologic body under study has a repetitive stratigraphy with blocks becoming smaller towards the bottom. In this way, it was possible to investigate the effects of the presence of the blocks on the mechanical behaviour of this complex geomaterial, by characterizing it and comparing the strength of the homogeneous material to that of the heterogeneous one.

A grading curve and the Atterberg limits were determined for both a homogeneous and a heterogeneous specimen. Furthermore, a mineralogical analysis was carried out to determine the mineral composition of the melange matrix. The results of these analyses indicate that the matrix is an inorganic clay of high plasticity and that it is mainly composed of quartz and calcite. Moreover, the clay represents more than 50% and 75% of the heterogeneous and only-matrix melange, respectively. Before performing the laboratory tests, the irregular lumps collected had to be regularized. Hence, they were cut with a specially made diamond band saw operating in dry conditions in order not to damage (i.e. to loosen) the matrix material. Moreover, the anisotropy of the matrix was taken into account during the cutting operations, creating the specimens with the planes of weakness, as much as possible, perpendicular to the direction of the load application. However, block detachments and fracture developments could not be completely avoided. As a consequence, only a few regular specimens could be obtained from more than 15 shapeless lumps. On these specimens, PLT and uniaxial compression tests were carried out, obtaining preliminary UCS values. In particular, 18 PLTs were performed on the heterogeneous samples. The load was applied perpendicularly to the planes of weakness in order to obtain the greatest strength values. The tests provided an average UCS of 2.5 MPa. This value is remarkably similar to those obtained with the uniaxial compression tests on two heterogeneous specimens, which yielded an average UCS of about 2.2 MPa. Even in this case the anisotropy of the melange was taken into account by applying the load perpendicularly to the planes of weakness. A smaller strength, of about 1.6 MPa, was determined from uniaxial compression tests for the only-matrix samples. This could be due to the absence of rock inclusions together with a greater number of planes of weakness. Moreover, the matrix-only and the block-in-matrix specimens provided extremely different failure surfaces, according to previous findings from the literature. An interesting question for future studies could be to determine how the presence of the anisotropy influences the mechanical behaviour of such geomaterials (i.e. failure surfaces and strength).

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