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TECHNICAL REPORT

TESTS ON PRECAST TUNNEL SEGMENTS WITH TRADITIONAL AND FIBERGLASS REINFORCEMENT

CUSTOMER: ATP S.p.A.

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DRAFT

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PREFACE

The loading tests, object of the present report, are carried out on precast tunnel segments, produced by UM&T, with fiberglass reinforcement produced by ATP.

The tests were conducted by the Material and Structural Laboratory of the Civil Engineering Department of the University of Rome Tor Vergata. Responsible of the tests are Prof. Zila Rinaldi and Prof. Alberto Meda.

Flexural tests were performed, as described in the following, in order to simulate the behavior of the segments when loaded under bending. In total, 3 segments have been tested, reinforced with traditional steel rebars and with fiberglass bars and fiberglass lattices, as described in the following.

1. SEGMENT GEOMETRY

The tests are carried out on precast tunnel segments.

The elements are characterised by a thickness of 400 mm, a length of about 4150 mm and a width of about 1483 mm (Fig. 1).

Three segment typologies have been tested, named, in the following, D4, D5 e D6

The segment D4 is characterised by a traditional steel cage made of 12+12Ø12 bars, placed in the intrados and extrados surfaces, with minimum cover of 50 mm (Fig. 2).

The reinforcement of the segment D5 is obtained by assembling fiberglass bars (12Ø12 +12Ø14 longitudinal bars, Fig. 3).

The reinforcement of the segment D6 is constituted by fiberglass lattices, made with 12Ø12 +12Ø14 longitudinal bars, as highlighted in Figure 4.

Figure 1. Segment geometry

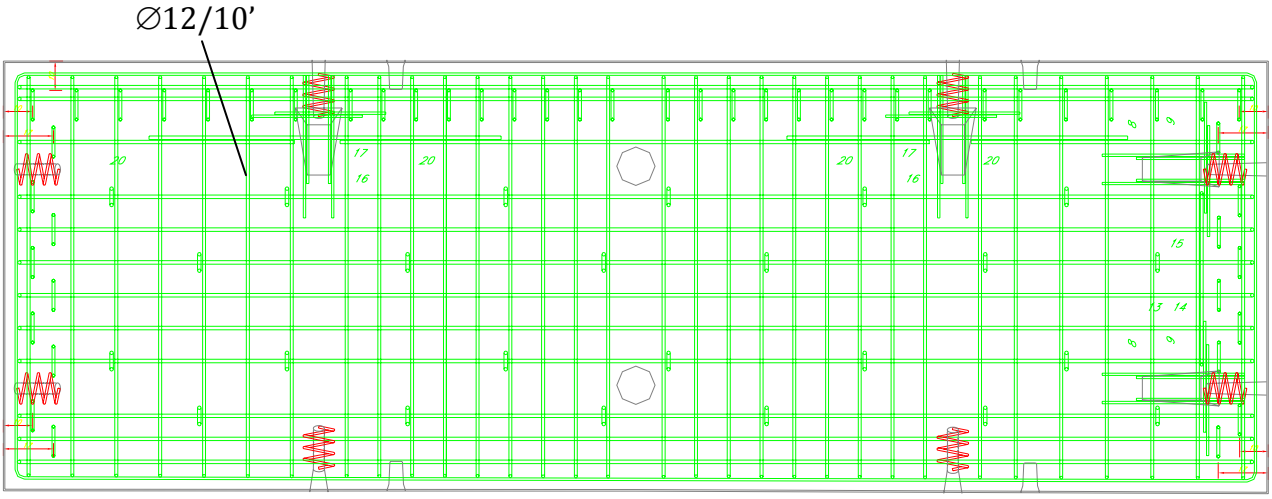


Figure 2. Segment D4: traditional steel cage

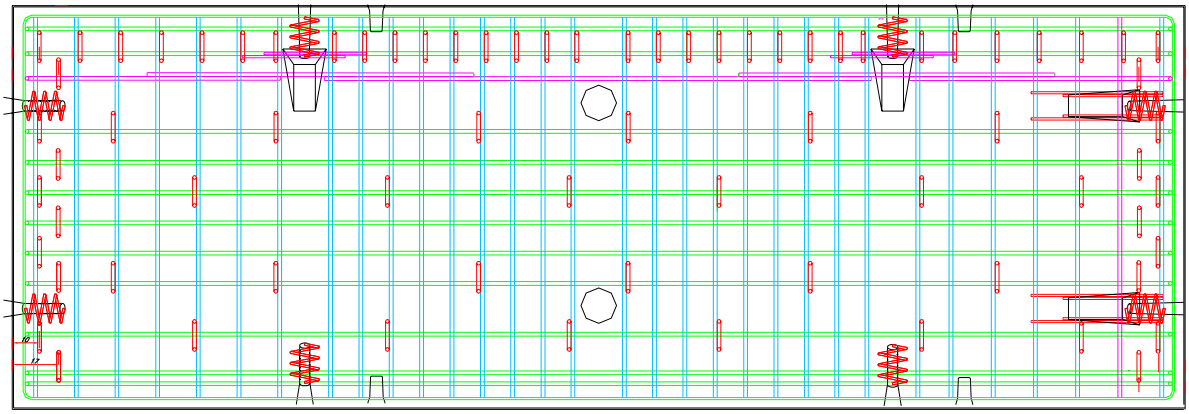


Figure 3. Segment D5: cage made fiberglass bars

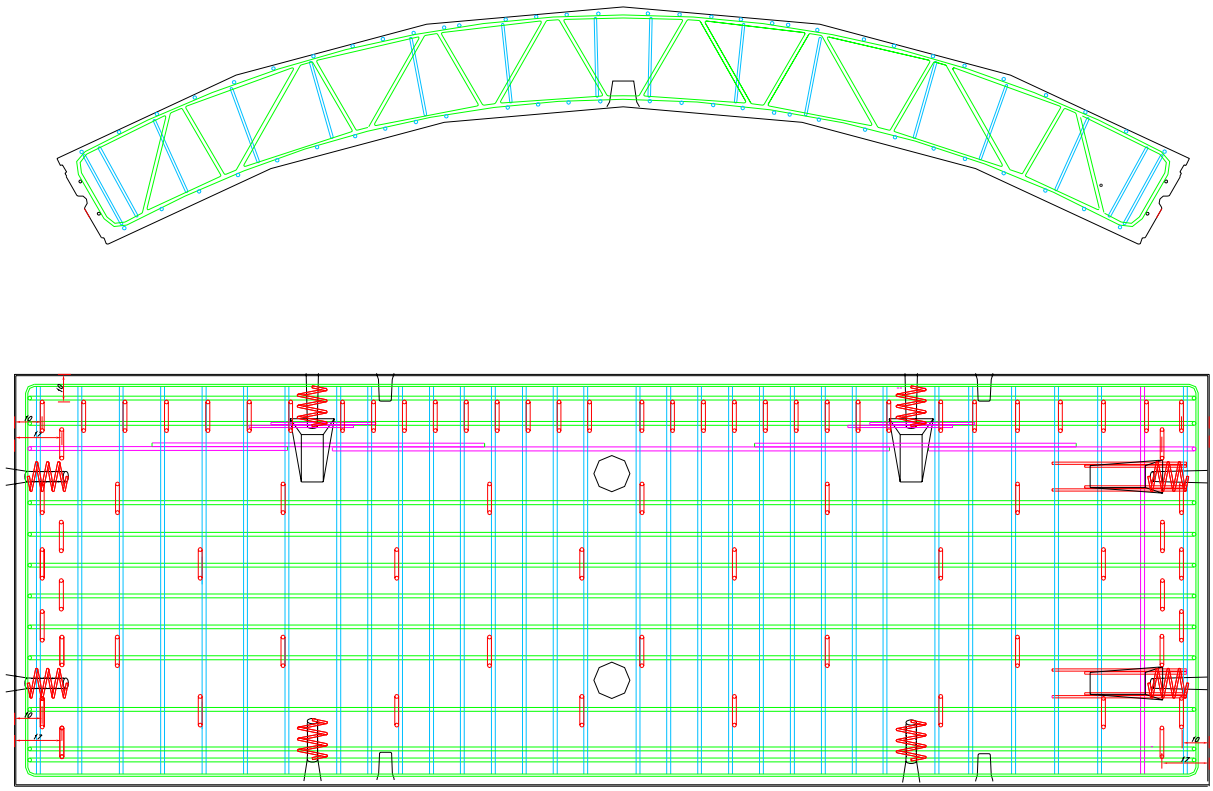


Figure 4. Segment D6: fiberglass lattices

2. BENDING TESTING PROCEDURE

The tests were performed with the loading set-up illustrated in Figure 5a and Figure 5b, in displacement control, under a contrast frame of 4000 kN (Fig. 6) by adopting a 1000kN electromechanical jacket, with a PID control and by imposing a stroke speed of 10 – 16 µm/sec.

The described phases have been followed:

1. Segment placement on the boundary system;
2. Assembling of the loading distribution system (Fig. 7);
3. First loading-unloading cycle up to 20 KN;
4. First loading-unloading cycle up to 100 KN;
5. Loading cycle up to the segment cracking;
6. Displacement increase up to the segment failure. Intermediate loading steps will be performed for the survey of the cracking pattern, as shown in the following.

The segments were placed on cylindrical support with a span of 3000 mm and the load, applied at midspan, was transversally distributed by adopting a steel beam as shown in Figures 6 and 7.

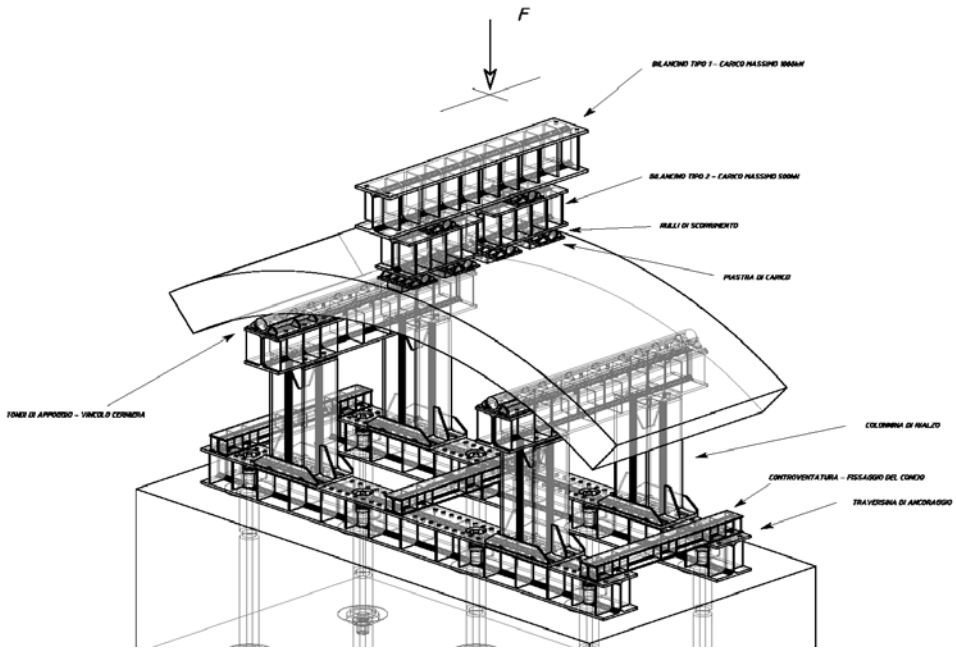


Figure 5a. Bending test set-up: scheme

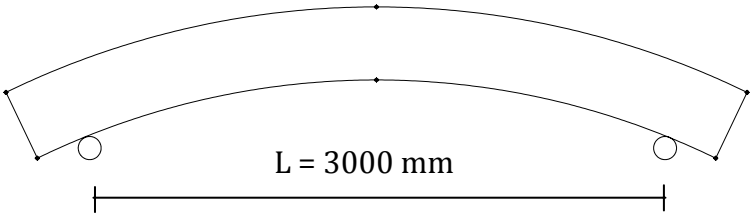
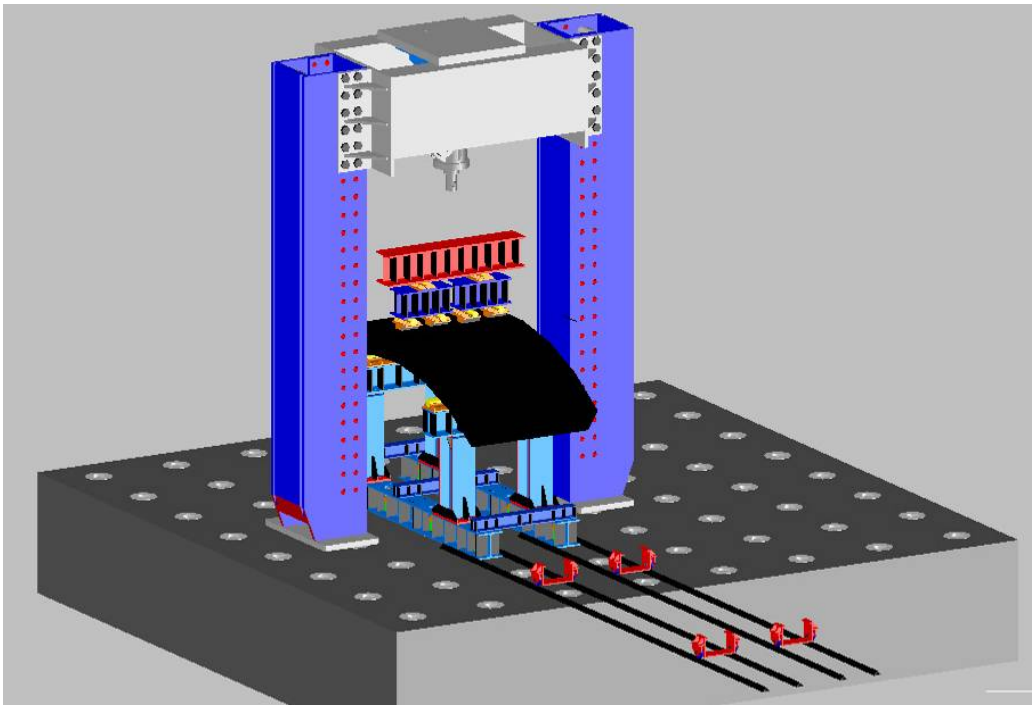


Figure 5b. Bending test set-up



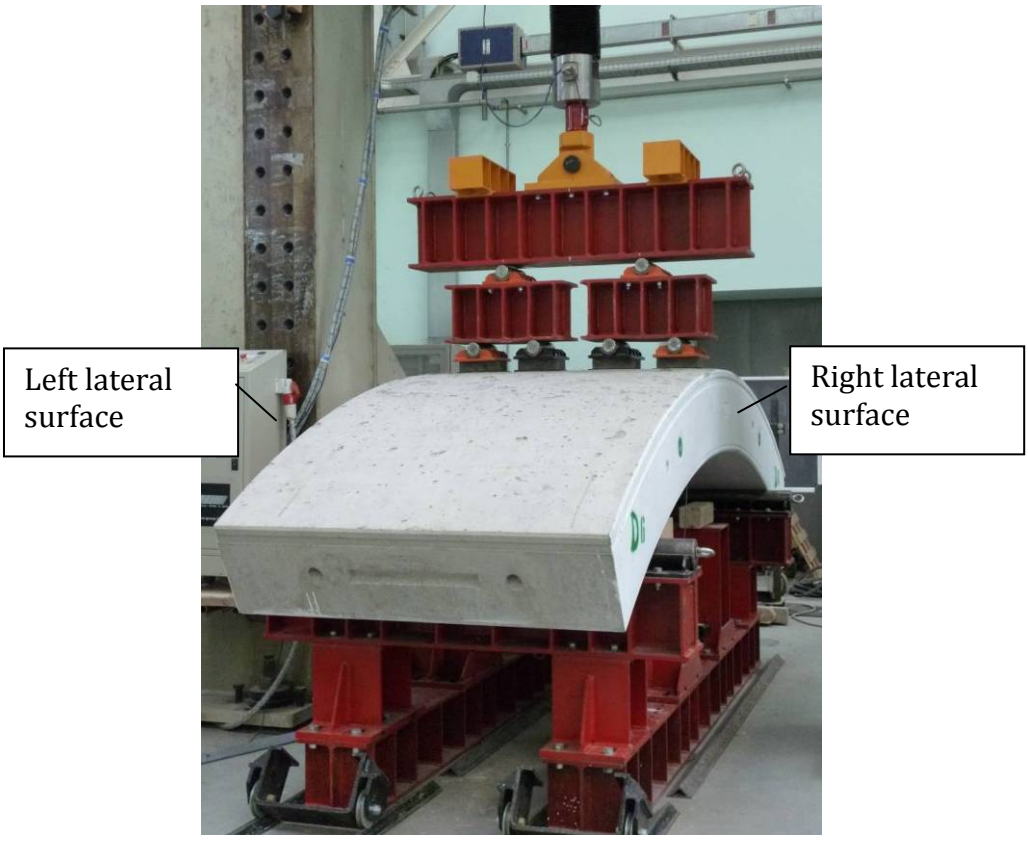


Figure 6. Segment under bending test

Figure 7. Loading distribution system

During the test, the following measures were continuously registered:

- the load F, measured by means of a 1000kN load cell with a precision of 0.2% (Fig. 6);
- the midspan displacement measured by means of three potentiometer wire transducers placed along the transverse line (Fig. 8);
- the crack opening at midspan, measured by means of two LVDTs (Fig. 8).

Furthermore, the crack pattern was recorded at different step, with the help of a grid plotted on the intrados surface (100x100mm, Fig. 9).

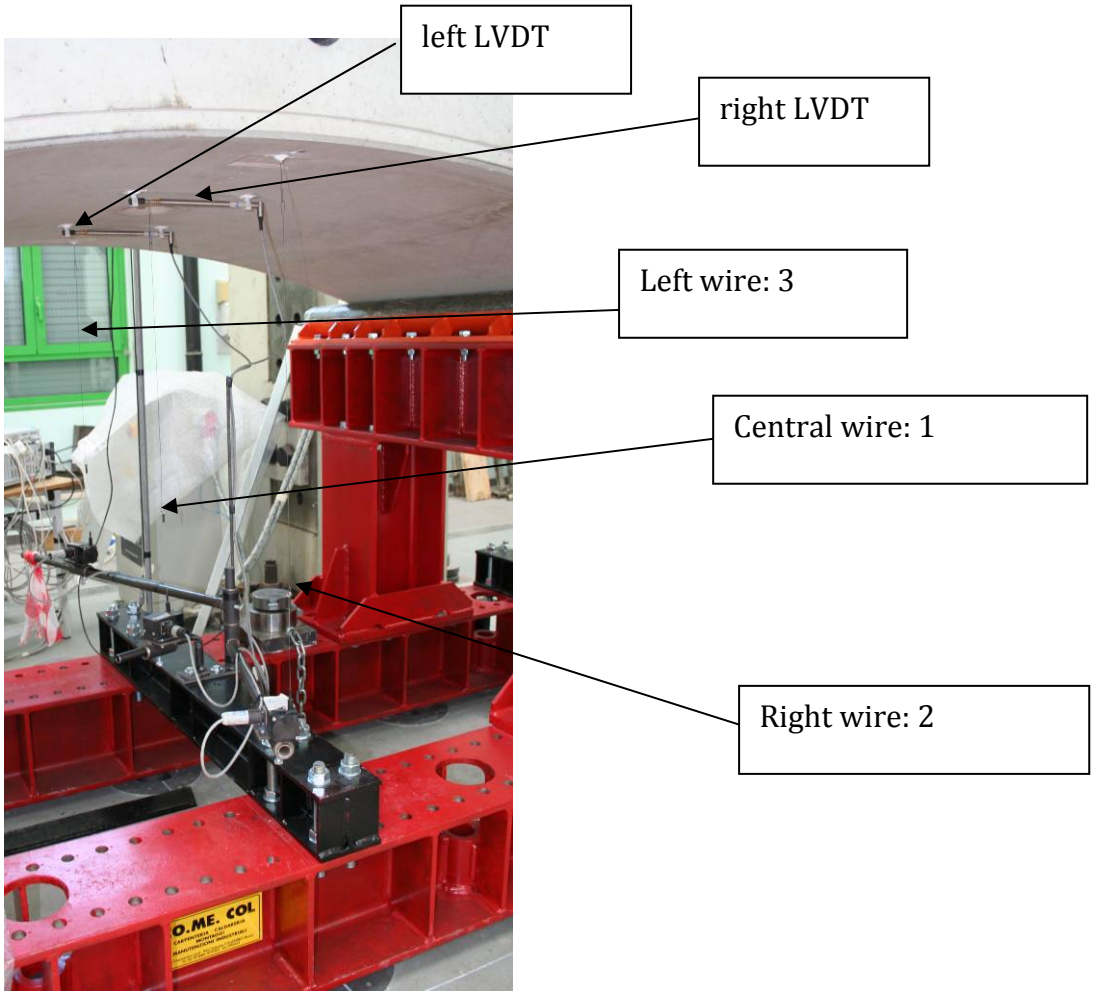


Figure 8. Bending test instrumentation

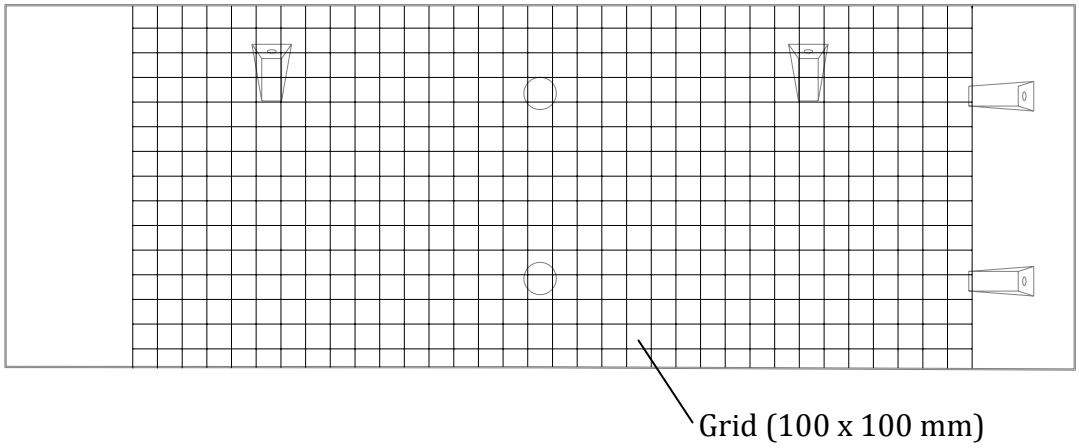


Figure 9. Grid on the intrados surface

3. RESULTS

3.1 Bending test on the segment D4

The results of the bending test on the segment D4, with traditional steel reinforcement, carried out the 23.1.2013 are here reported.

The bending test set up is highlighted in Figure 10.

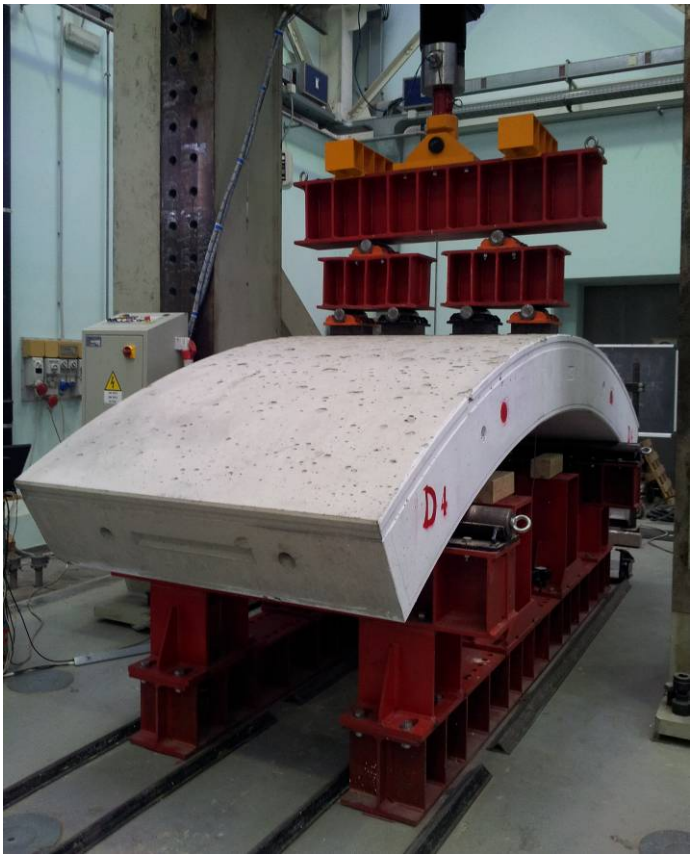


Figure 10. Segment D4: Test set-up

The test procedure and the adopted instrumentation have been described in the previous paragraph.

In Figure 11 it is plotted the load – displacement relationship related to the wire transducers (Fig. 8).

It is worth remarking that the three instruments, located in the midspan, measured almost coincident displacement values, highlighting a homogeneous behaviour of the segment in this direction.

The **maximum load** is equal to about 395 kN.

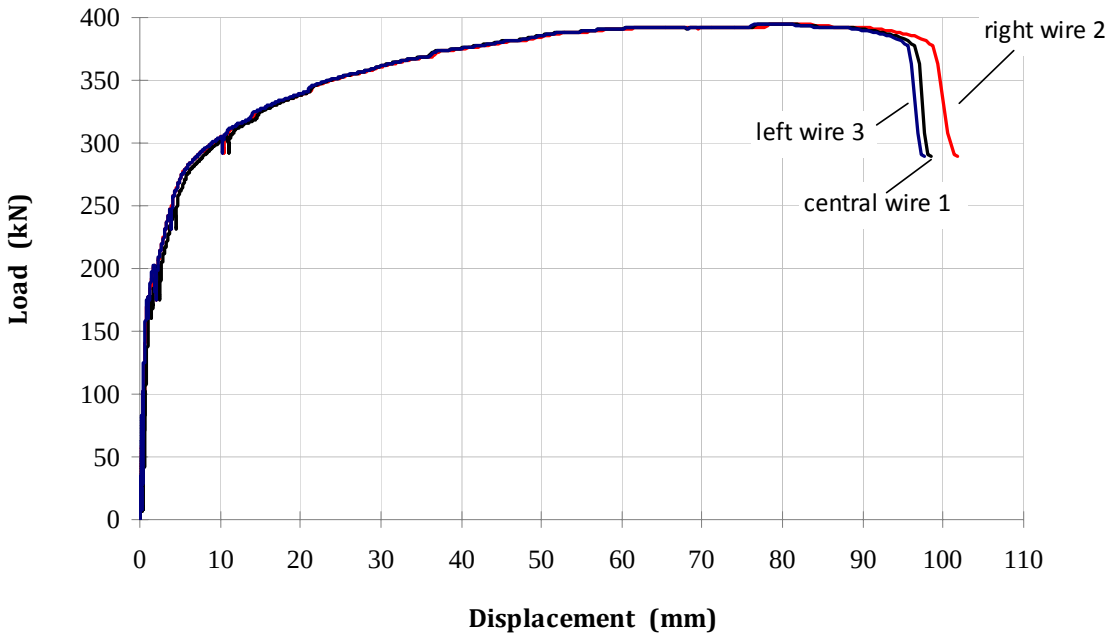


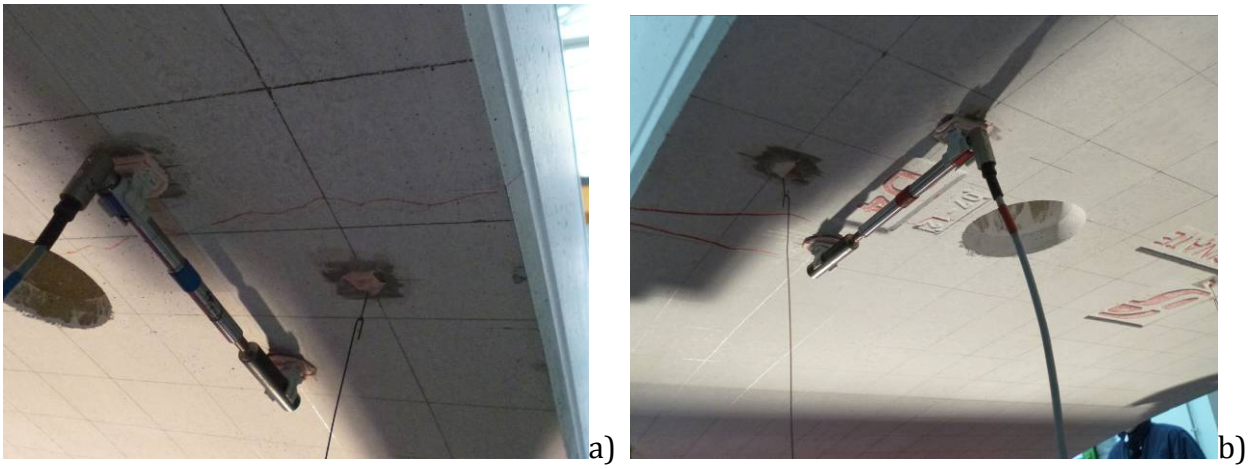
Figure 11. Segment D4: Load –Displacement diagram

The first cracks opened for a load value of about 175 kN close to the midspan of the segment on the lateral and intrados surfaces (Figs. 12 and 13).


a)

b)

Figure 12. Segment D4: load level of 175 kN; a) left lateral surface, b) right lateral surface

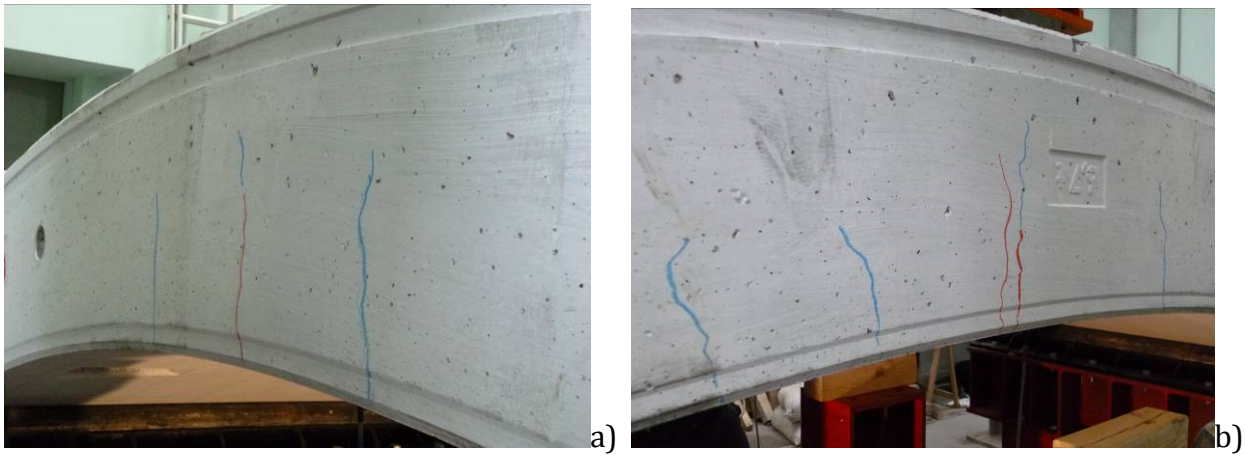


a) b)

Figure 13. Segment D4: load level of 175 kN – intrados surface; a) left side; b) right side

The crack pattern on the lateral and intrados surfaces, for a load level of 200 kN is highlighted in Figures 14 and 15. The maximum crack width is equal to 0.3 mm, as shown in Figure 16.

The crack distribution for a load level of 300 kN is highlighted in Figures 17 and 18. The maximum crack width is equal to about 3 mm, as shown in Figure 19.



a) b)

Figure 14. Segment D4: load level of 200 kN; a) left lateral surface, b) right lateral surface

Figure 15. Segment D4: load level of 200 kN, intrados surface

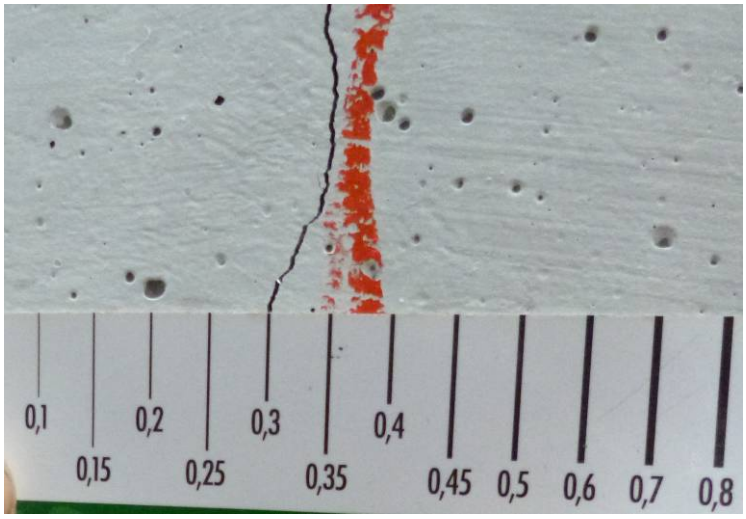
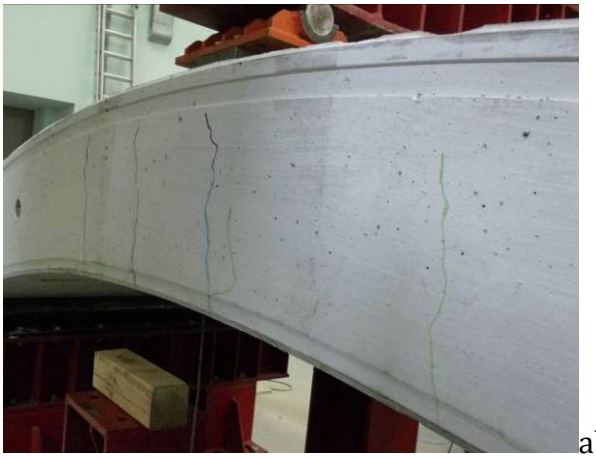


Figure 16. Segment D4: load level of 200 kN, maximum crack width.


a)

b)

Figure 17. Segment D4: load level of 300 kN; a) left lateral surface, b) right lateral surface.

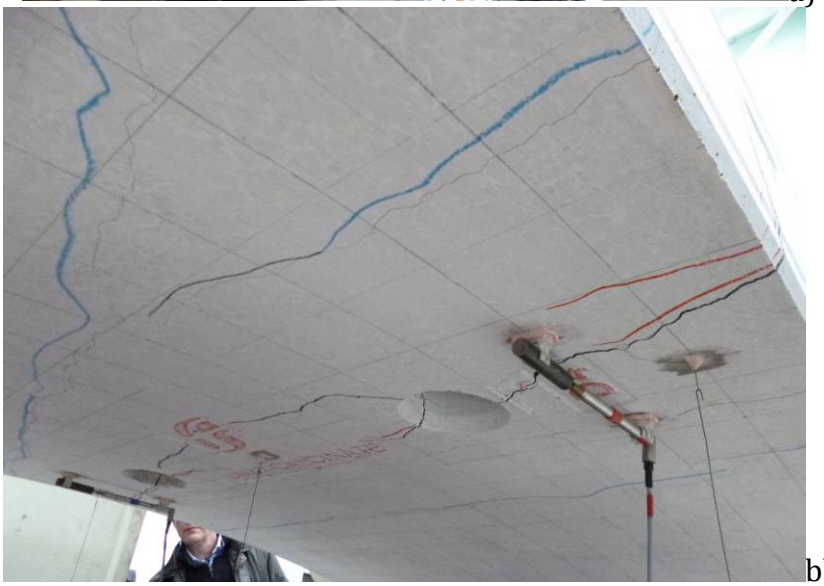

a)

b)

Figure 18. Segment D4: load level of 300 kN – intrados surface; a) left side; b) right side

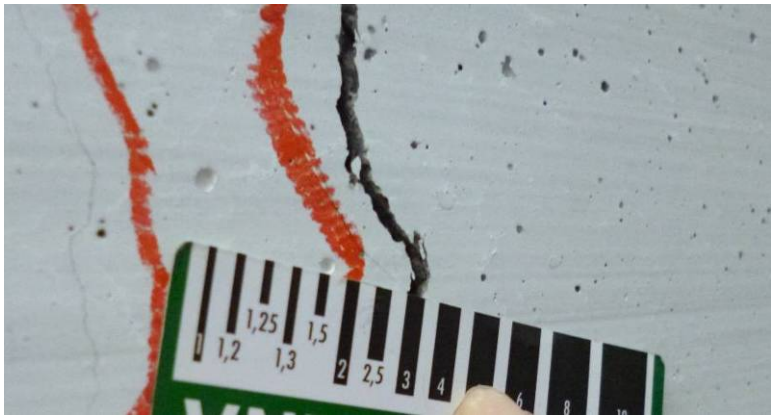


Figure 19. Segment D4: load level of 300 kN, maximum crack width.

The crack pattern related the ultimate state is plotted in Figures 20 and 21. The final crack pattern, at the end of the test is summarised in Figure 22.

a)

b)

Figure 20. Segment D4: failure stage a) left lateral surface, b) right lateral surface.

Figure 21. Segment D4: failure stage: intrados surface.

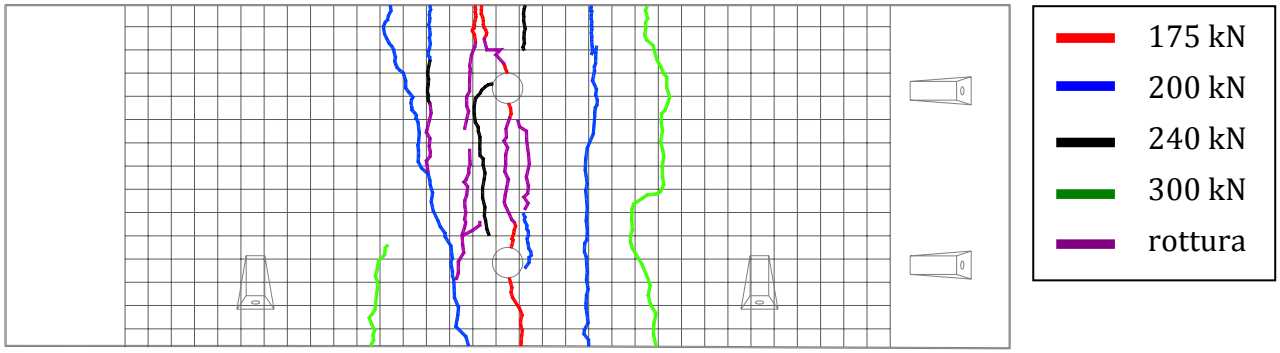


Figure 22. Segment D4: final crack pattern

The crack width is evaluated on the basis of the two LVDTs measures. In Figure 23 the LVDTs displacements are plotted versus the load.

The measured values refer to the one main crack that gets across the instruments (Fig. 18).

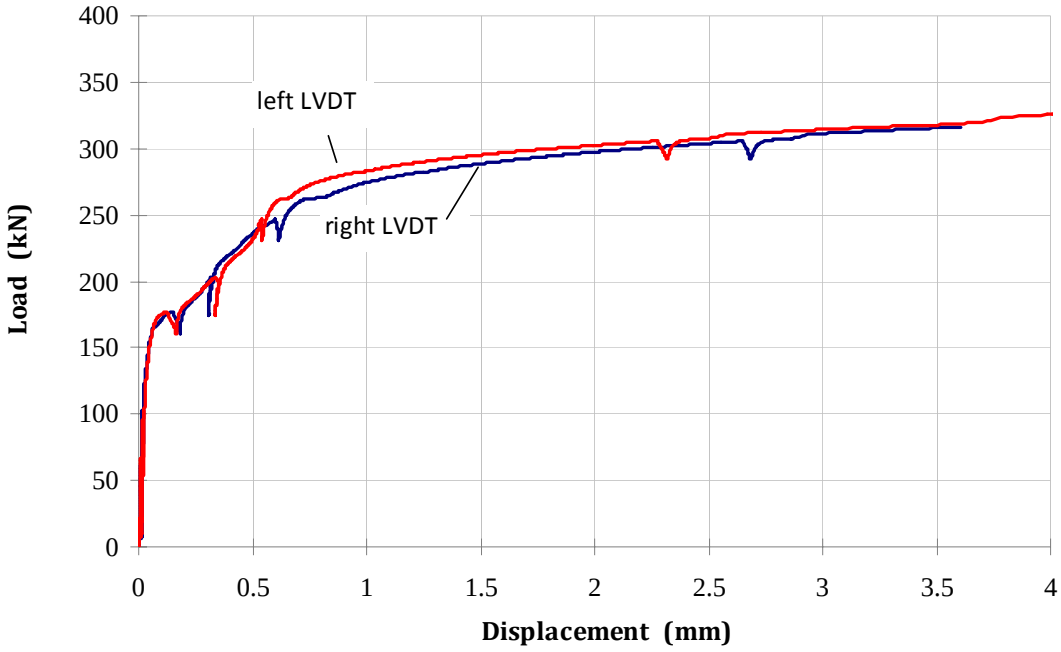


Figure 23. Segment D4. Force-displacement diagram (LVDTs)

3.2 Bending test on the segment D5

The results of the bending test on the segment D5, with fiberglass bars, carried out the 24.1.2013, are here reported.

The bending test set up is highlighted in Figure 24.

Figure 24. Segment D5: Test set-up

The test procedure and the adopted instrumentation have been described in Paragraph 2.

In Figure 25 it is plotted the load – displacement relationship related to the wire transducers (Fig. 8).

It is worth remarking that the three instruments, located in the midspan, measured very similar displacement values, highlighting a homogeneous behaviour of the segment in this direction.

The **maximum load** is equal to about 640 kN.

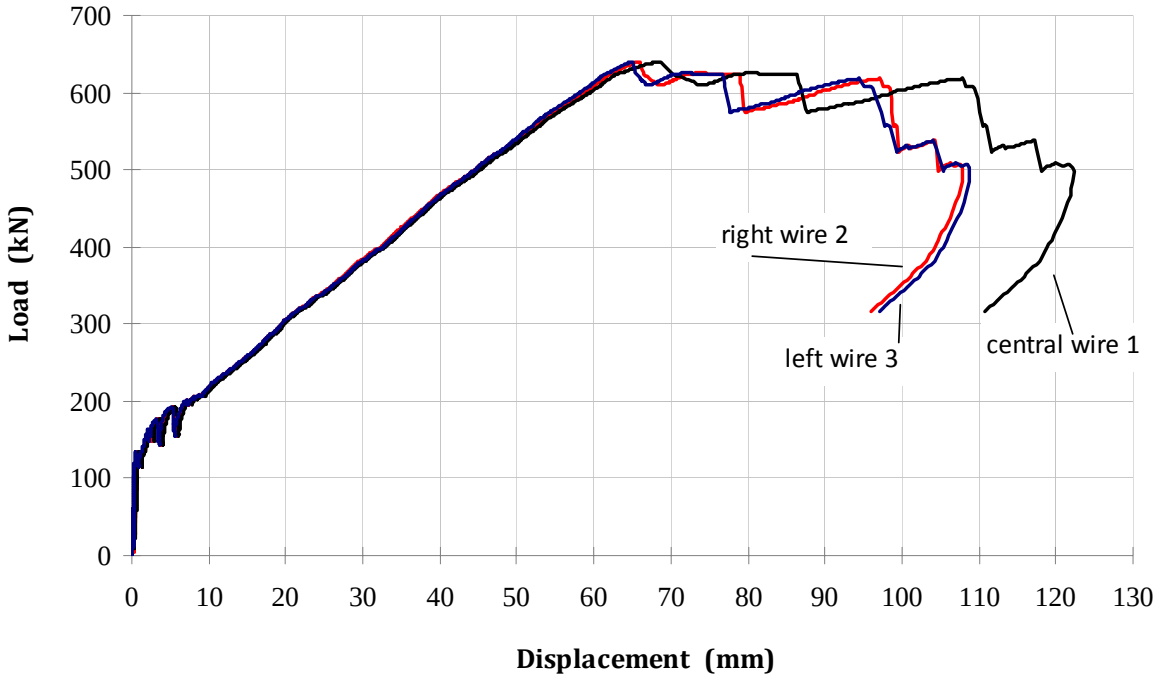


Figure 25. Segment D5: Load –Displacement diagram

The first cracks opened for a load value of about 130 kN close to the midspan of the segment on the lateral and intrados surfaces (Figs. 26 and 27).


a)

b)

Figure 26. Segment D5: load level of 130 kN; a) left lateral surface, b) right lateral surface


a)


b)


c)

Figure 27. Segment D5: load level of 130 kN intrados surface(a); b) left side; c) right side

The crack pattern on the lateral and intrados surfaces, for a load level of 160 kN is highlighted in Figures 28 and 29. The maximum crack width is equal to 0.7 mm, as shown in Figure 30.

The crack distribution for a load level of 195 kN is highlighted in Figures 31 and 32. The maximum crack width is equal to about 1.3 mm, as shown in Figure 33.


a)

b)

Figure 28. Segment D5: load level of 160 kN; a) left lateral surface, b) right lateral surface

Figure 29. Segment D5: load level of 160 kN, intrados surface

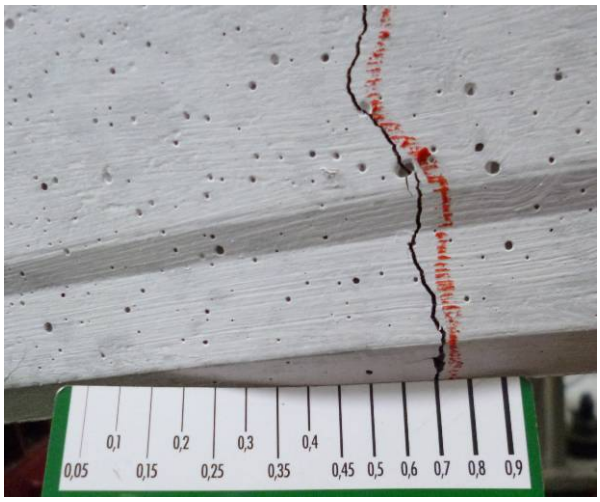


Figure 30. Segment D5: load level of 160 kN, maximum crack width.

a)

b)

Figure 31. Segment D5: load level of 195 kN; a) left lateral surface, b) right lateral surface.

a)

b)

Figure 32. Segment D5: load level of 195 kN – intrados surface

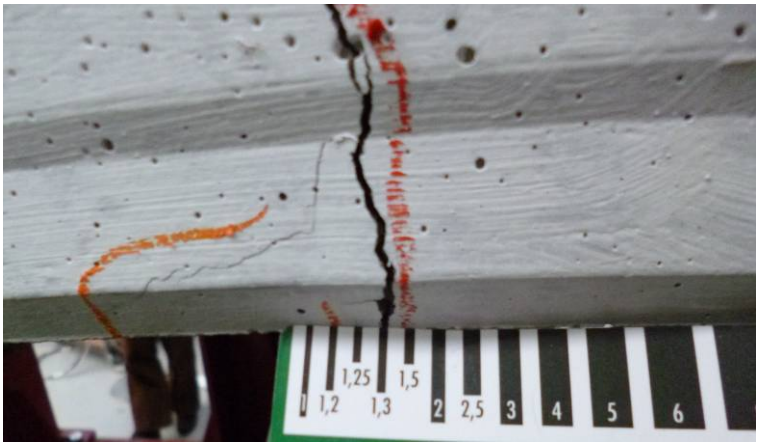


Figure 33. Segment D5: load level of 195 kN, maximum crack width.

The crack pattern related the ultimate state is plotted in Figures 34, 35 and 36. The final crack pattern, at the end of the test is summarised in Figure 37.

Figure 34. Segment D5: failure stage: right lateral surface.

Figure 35. Segment D5: failure stage: left lateral surface.

Figure 36. Segment D5: failure stage: intrados surface.

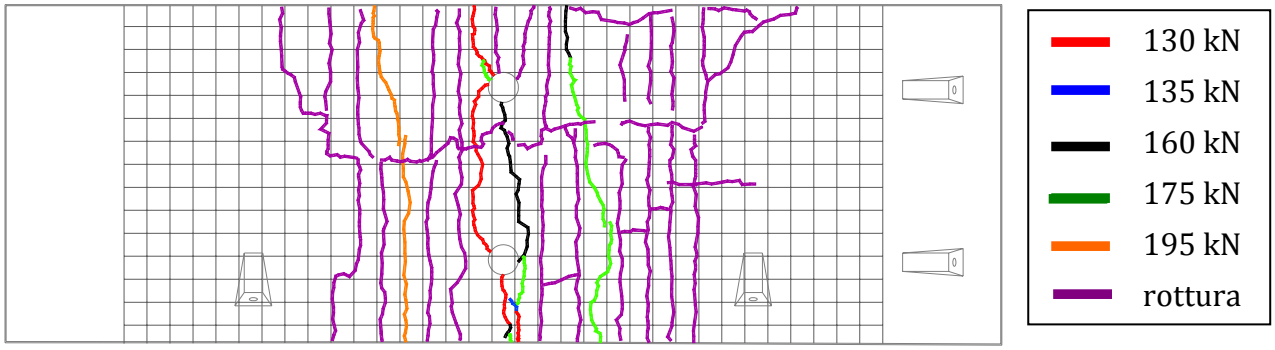


Figure 37. Segment D5: final crack pattern

Unfortunately the LVDTs were soon detached (for a crack passing through their supports) and their measures were not recorded.

3.3 Bending test on the segment D6

The results of the bending test on the segment D6, with fiber-glass lattices, carried out the 23.1.2013 are here reported.

The bending test set up is highlighted in Figure 38.

Figure 38. Segment D6: Test set-up

The test procedure and the adopted instrumentation have been described in Paragraph 2.

In Figure 39 it is plotted the load – displacement relationship related to the wire transducers (Fig. 8). The left wire 3 was detached for a load value of about 600 kN.

It is worth remarking that the three instruments, located in the midspan, measured almost coincident displacement values, highlighting a homogeneous behaviour of the segment in this direction.

The **maximum load** is equal to about 881 kN.

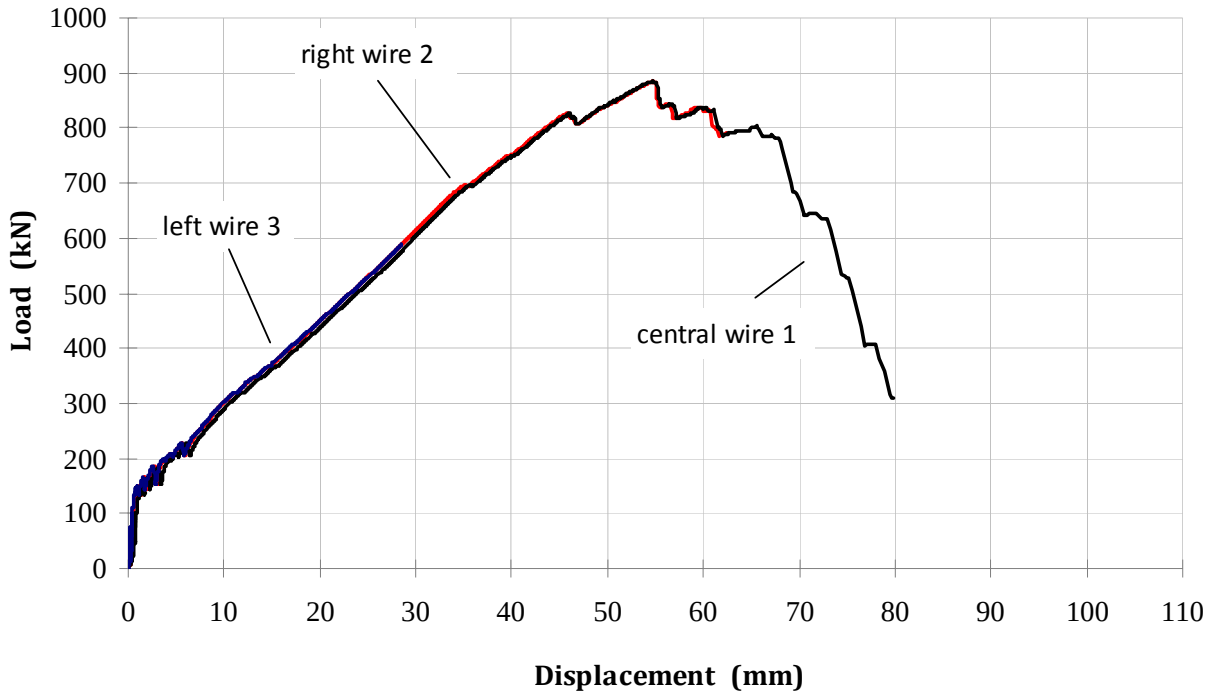
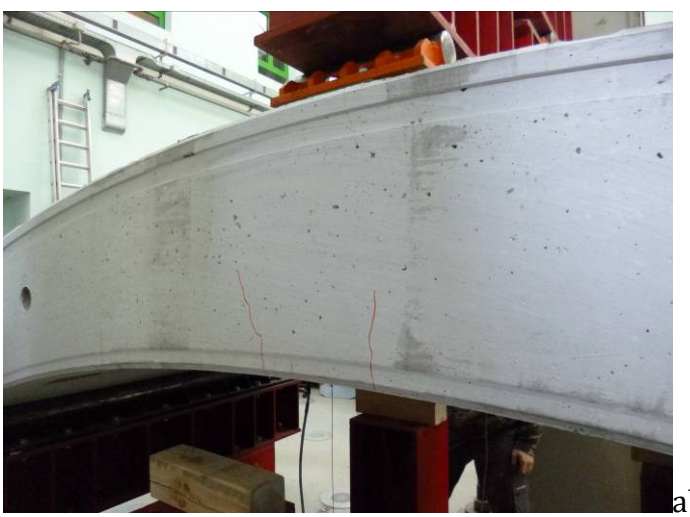


Figure 39. Segment D6: Load –Displacement diagram

The first cracks opened for a load value of about 140 kN close to the midspan of the segment on the lateral and intrados surfaces (Figs. 40 and 41).


a)

b)

Figure 40. Segment D6: load level of 140 kN; a) left lateral surface, b) right lateral surface

Figure 41. Segment D6: load level of 140 kN intrados surface

The crack pattern on the lateral and intrados surfaces, for a load level of 164 kN is highlighted in Figures 42 and 43. The maximum crack width is equal to 0.7 mm, as shown in Figure 44.

The crack distribution for a load level of 185 kN is highlighted in Figures 45 and 46. The maximum crack width is equal to about 3 mm, as shown in Figure 47.


a)

b)

Figure 42. Segment D6: load level of 164 kN; a) left lateral surface, b) right lateral surface

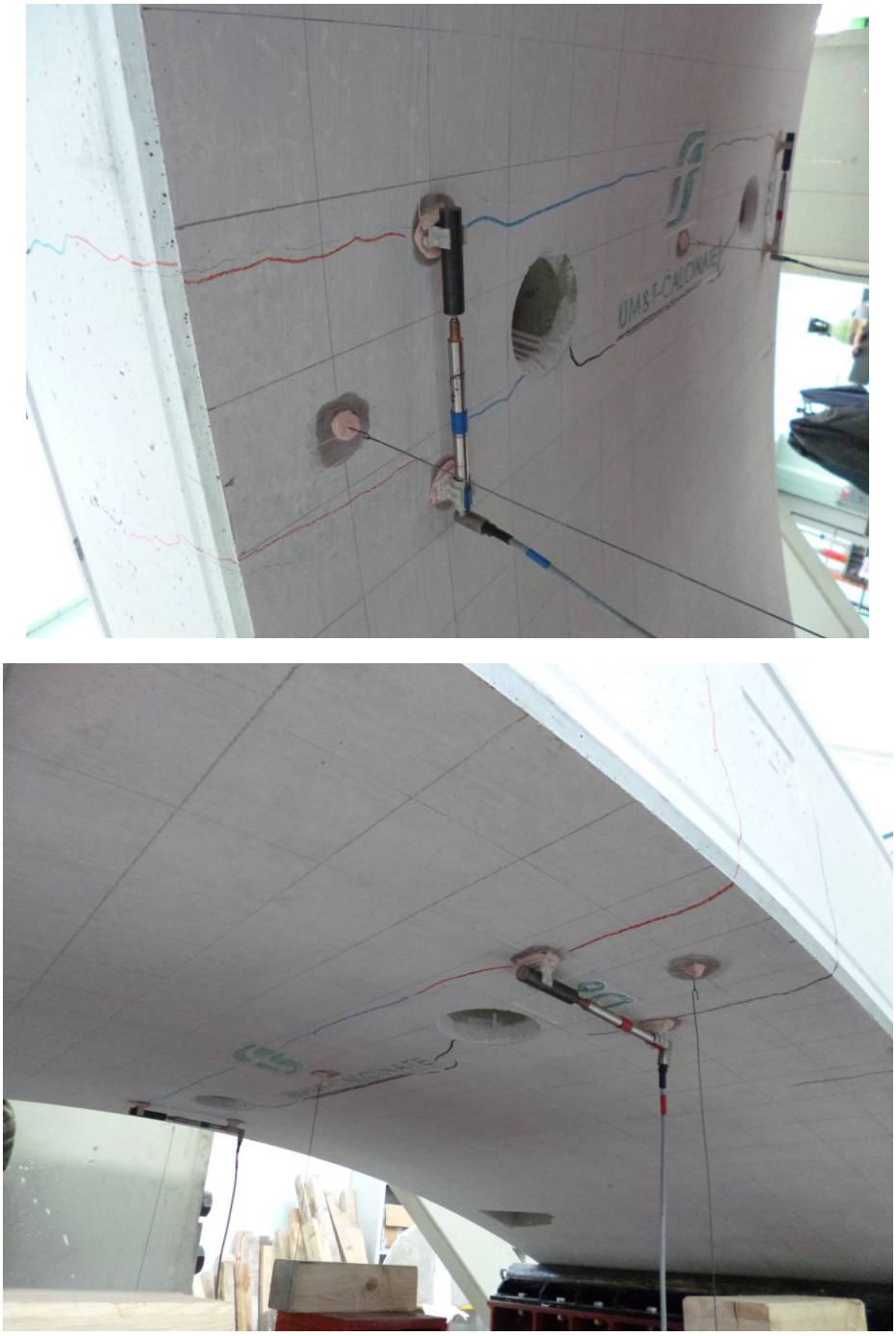


Figure 43. Segment D6: load level of 164 kN, intrados surface

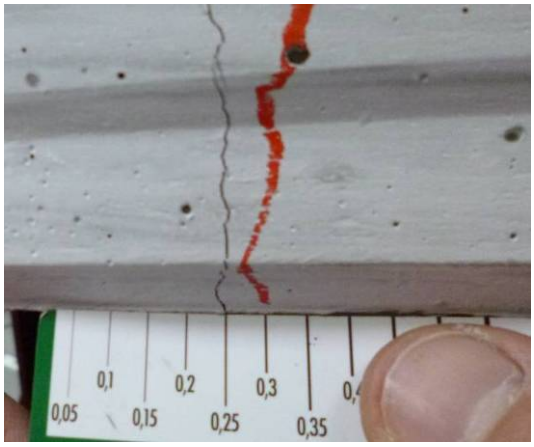


Figure 44. Segment D6: load level of 164 kN, maximum crack width.


a)


b)

Figure 45. Segment D6: load level of 185 kN; a) left lateral surface, b) right lateral surface.

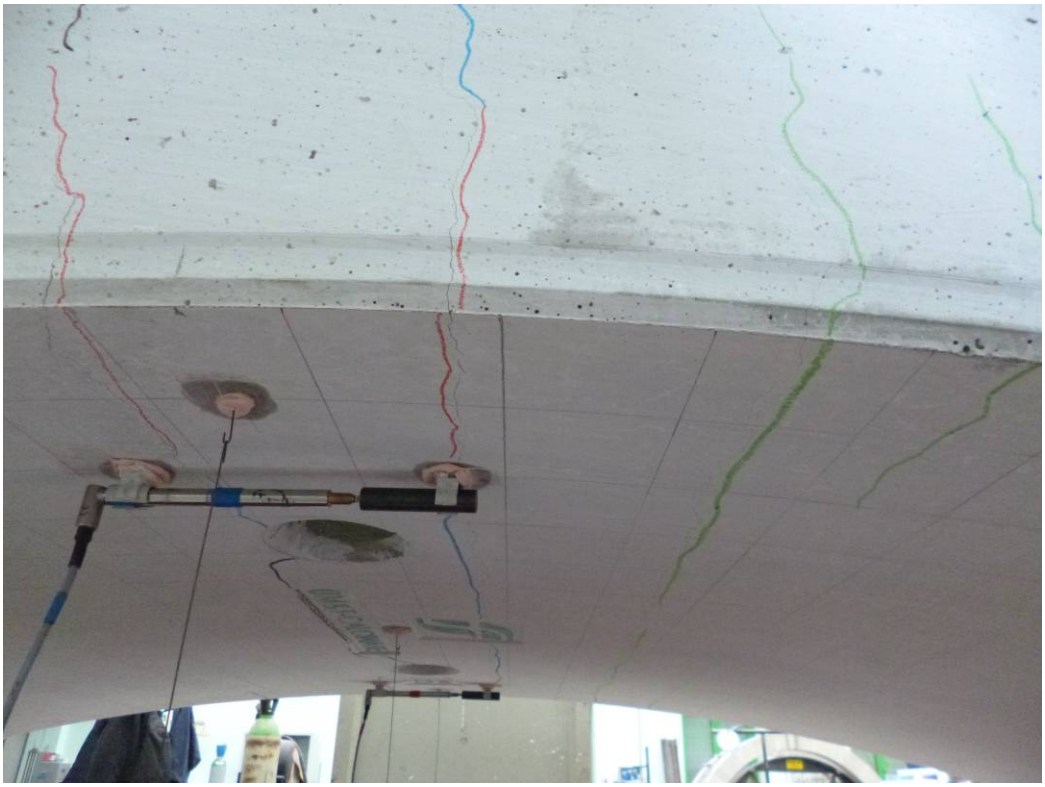


Figure 46. Segment D6: load level of 185 kN – intrados surface

Figure 47. Segment D6: load level of 185 kN, maximum crack width.

The crack pattern related the ultimate state is plotted in Figures 48, 49 and 50. The final crack pattern, at the end of the test is summarised in Figure 51.

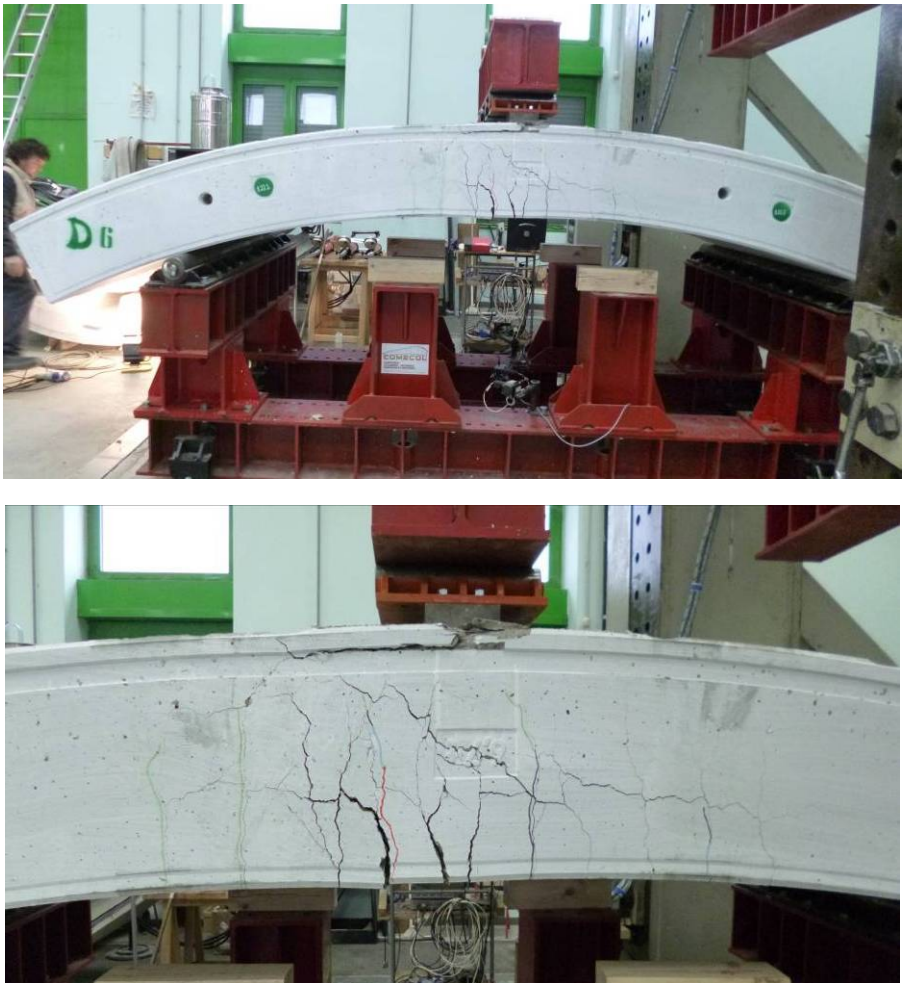


Figure 48. Segment D6: failure stage: right lateral surface.

Figure 49. Segment D6: failure stage: left lateral surface.

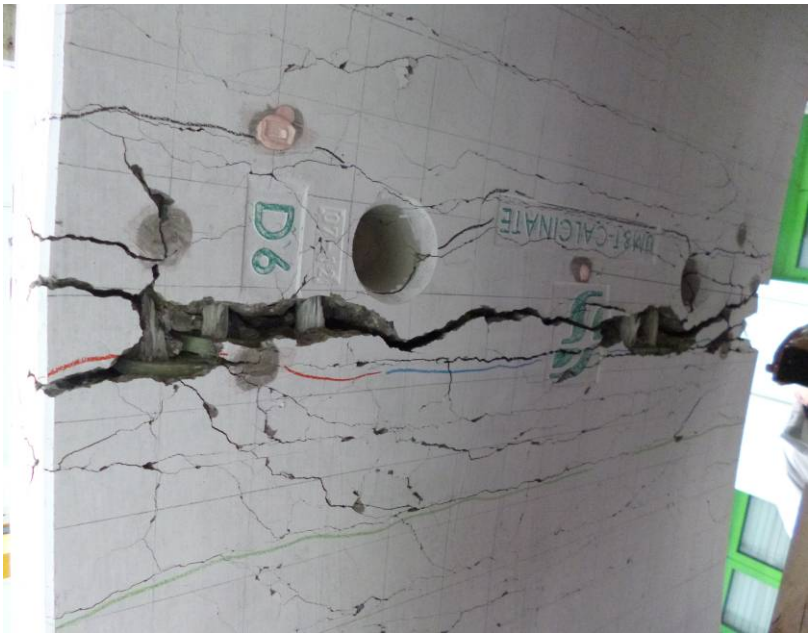


Figure 50. Segment D6: failure stage: intrados surface.

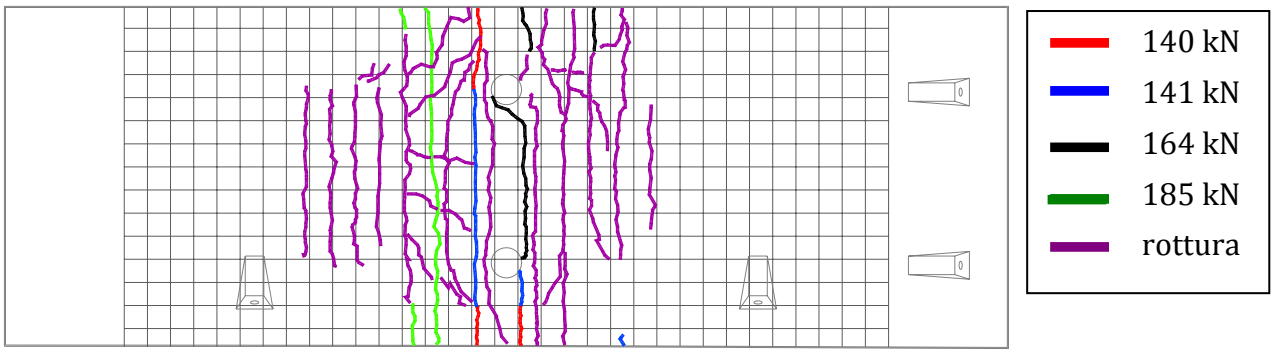


Figure 51. Segment D6: final crack pattern

Unfortunately the LVDTs were soon detached (for a crack passing through their supports) and their measures were not recorded.

CONCLUSIONS

The technical report shows the results three bending tests carried out in the Laboratory of the University of Rome "Tor Vergata" on precast segments with traditional and fiber glass reinforcement.

The load –displacement diagrams and the evolution of the crack pattern are highlighted and pictures related to each test are summarised in this report.

Roma, 12.02.2013

Prof. Ing. Alberto Meda

Prof. Ing. Zila Rinaldi