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Structural Integrity Procedia 00 (2022) 000–000

Structural Integrity Procedia

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II Fabre Conference – Existing bridges, viaducts and tunnels: research, innovation and applications (FABRE24)

A preliminary investigation on material properties of existing prestressed concrete beams

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Abstract

This paper reports some preliminary results of an ongoing research activity addressed to collect and to elaborate the main mechanical properties of materials of pre- and post-tensioned concrete girder bridges. In particular, in this work data samples is obtained by analyzing design documents of a stock of existing bridges realized in Basilicata (south of Italy). At first, the paper presents a proposal on how information available is collected. Then, results of the statistical elaborations on the samples gathered are shown, in order to provide useful support in estimating the mechanical properties of the materials used in the bridges typologies considered in this study.

Keywords: pre-tensioned concrete beams; post-tensioned concrete beams; existing bridges; knowledge; material properties; statistical analysis.

1. Introduction

Prestressed Concrete (PC) is a concrete subjected to compressive forces provoking internal stresses for counteracting external loads effects to a desired degree. It may be obtained either pre- or post-tensioning concrete

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beams by means of steel tendons applied, respectively, before or after element curing. In the case of post-tensioning, tendon consists of anchorages and couplers, prestressing steel, and sheathing or duct with coating grease for unbonded applications or grouted ducts, grout caps, and grout vents for bonded applications. Several factors may influence PC efficiency such as, among the others, the structural component, natural environment, scarce or absent maintenance, prestressing technique, construction practices. To this it should be added that, despite its advantages, corrosion durability problems may plague the PC technology.

For these reasons, and also due to some sudden structural failures, there has been an increasing interest in studying existing Prestressed Concrete Beams (PCBs) especially applied in Reinforced Concrete (RC) girder bridges. However, since designed and realized many years ago (most of them are at least 50 years old), to date knowledge of these structures is essential in order to properly evaluate their current capacity under design loads. To this scope, materials details, without any doubt, are a fundamental step within the knowledge process. Moreover, material and structural details may have recurrent properties within a certain geographic area, or also along the same serving road if consecutives bridges were realized according to the same construction rules/practices.

Therefore, this work is addressed to create a valid tool for improving the knowledge of existing RC girder bridges with PCBs. To this aim, a database collecting the main materials mechanical properties of several girder bridges with PCBs is implemented and analyzed. The database is created from a territorial case study, consisting of several pre- and post-tensioned RC girder bridges realized between 1960-2000, and belonging to Italian roads located into the Basilicata region (south of Italy). In total, about no. 98 bridges serving no. 1 Highway Junction (HJ), no. 9 State Roads (SRs) and no. 1 Provincial Road (PR) are examined, archiving the main mechanical properties of concrete, steel for reinforcing bars and prestressing steel of each bridge considered. In detail, database collects: design nominal values retrieved from original design documentation (such as drawings and reports), mechanical values measured during the structures execution and reported within acceptance test certificates, and in-situ tests recently performed. For completeness, database also reports information related to each bridge considered, such as: construction year, prestressing technology adopted (pre- or post-tensioning), bridge category declared, and structural element to which materials mechanical properties recorded are belonging. At first, a brief state of art review is reported recalling Italian reference design standards for existing constructions. Then, preliminary results in terms of strength classes percentages within the database obtained are shown and commented. They may provide a useful support within the knowledge process of an existing RC girder bridge with PCBs, in order to estimate the most recurrent mechanical properties applied in the territorial case study considered.

2. Reference standards

2.1. Reinforcing steel

Since the early 1900s Italian legislation regulated mechanical characteristics of steels of RC constructions (Verderame et al. 2001a). In particular, Ministerial Degree 10/01/1907 (M.D., 1907) reported the first technical standards, ending the nineteenth-century era approach for constructions where their safety was guaranteed only by compliance with technical rules without numerical checks obligation. In contrast to this standard, the same M.D. introduced numerical verifications for constructions under Public Works Ministry competence only. Afterwards, in 1925 this obligation was extended to all Italian authorities constructions. Royal Decree of 16/11/1939 no. 2228-2232 (R.D., 1939) regulated use of smooth bars as concrete reinforcement remaining in force until 1972. It classified reinforcing steel in three categories in accordance with its carbon content, that were: mild, medium, and high strength. Circular no. 1472 of 23/05/1957 issued by Public Works Ministry (M.P.W., 1957) adopted the same prescriptions of R.D. 1939 for steel of smooth reinforcing bars but modifying its nomenclature. In this document three steel categories were considered, that were Aq. 42, Aq. 50 and Aq. 60 having mechanical characteristics equivalent to mild, medium and high strength steel of the R.D. 1939. In addition, in this Circular also ribbed bars were introduced for the first time. Only with Ministerial Decree 30/05/1972 (M.D., 1972) steel categories were substantially changed, distinguishing between smooth bars classes (such as FeB22 and FeB32), and ribbed bars classes (A38, A41 and FeB44) (M.D., 1972). Then, in Ministerial Decree of 30/05/1974 (M.D., 1974) this classification was confirmed for smooth bars, while for ribbed bars only A38 steel was replaced by FeB38. For completeness, a comparison among different Italian steel classifications is reported in Table 1.

Table 1. Comparison among different Italian steel classifications adopted by several design code.

Design code	R.D. no. 2229/1939			M.P.W. no.1472/1957				M.D. 30/05/1972					M.D. 30/05/1974			
Typology	smooth			smooth			ribbed	smooth		ribbed			smooth		ribbed	
Denomination	Mild	Medium	ALE	Aq. 42	Aq. 50	Aq. 60		FeB22	FeB32	A38	A41	FeB44	FeB22	FeB32	FeB38	FeB44
Yielding strength [kg/mm^2]	≥23	≥27	≥31	≥23	≥27	≥31	/	≥22	≥32	≥38	≥41	≥44	≥22	≥32	≥38	≥44
Tensile strength [kg/mm^2]	42-50	50-60	60-70	42-50	50-60	60-70	/	≥34	≥50	≥46	≥50	≥55	≥34	≥50	≥46	≥55
Ultimate elongation A_{10} [%]	≥20	≥16	≥14	≥20	≥16	≥14	≥12	≥24	≥23	≥14	≥14	≥12	≥24	≥23	≥14	≥12

2.2. Concrete

Over the years several Italian standards were issued for acceptance requirements of cements and hydraulic binders, that even nowadays are considered during the execution as reference for certificating and controlling cementitious materials. In the 1960s the most frequently used classes were R250, R350, R500, R600, and R730, where the number indicates the compressive strength expressed in kg/cm^2 at 28 days (Verderame et al. 2001b). As for the method for determining the compressive strength, Royal Decree 4/9/1927 (R.D., 1927) calculated it as the average compressive strength evaluated on four cubic specimens, verifying that each strength had not to be less than the average by more than 20%. The safety load did not have to exceed one-fourth of the 28 days compressive strength, 30 kg/cm^2 for second-quality cements, and 40 kg/cm^2 for first-quality cements. Royal Degree 23/5/1932 (R.D., 1932) the compressive strength had to be evaluated on four specimens, and the average had to be calculated among the three highest ones. The same criteria were also used in R.D. 1939 where, however, the compressive strength must, however, never be less than 120 kg/cm^2 for normal cement mixtures and 160 kg/cm^2 for high-strength and aluminous cement mixtures. A substantial modification of acceptance criteria for concrete strength was introduced in Ministerial Decree 30/5/1972 (M.D., 1972), where 4 cubic specimens every 100 m^3 were required, and the strength was evaluated as the average value of the specimen compressive strengths.

2.3. Prestressing steel

M.D. 30/05/1972 (1972) indicated for the first time mechanical properties of prestressing steel, either for pre-tensioning (with adherent wires) or for post-tensioning (with a sliding cables) concrete elements. Mechanical properties considered were: tensile strength (f_{ptk}), tensile strength at 0.1% of residual deformation [$f_{p(0,1)k}$], tensile strength at 0.2% of residual deformation [$f_{p(0,2)k}$], strength at 1% of total deformation [$f_{p(1)k}$], elongation at the maximum strength (A_{gt}), and the maximum allowable stress (σ_s). Afterwards, Ministerial Degree 30/05/1974 (M.D., 1974) reported also indications on sampling, indicating at least n. 10 samples for calculating the strength average value.

Prestressing steel for PCBs may be used in several elements, such as wires, bars, strands and braids, which are shown in Fig. 1 Wire generally has a diameter between 2 and 5 mm. Bar is rolled with a solid section, supplied only in a straight form, with a diameter between 15-40 mm. Strand is generally made by 6 drawn wires wound in a helix around a central drawn wire, with a diameter between 13-15 mm. Braid is made up of 2 or 3 drawn wires wound in a helix, without a central core, with a diameter between 50-70 mm. In Italy, prestressing system with adherent wires was used for bridge beams with a span of even more than 40 m, generally using half-inch strands (Guidi, 1987).

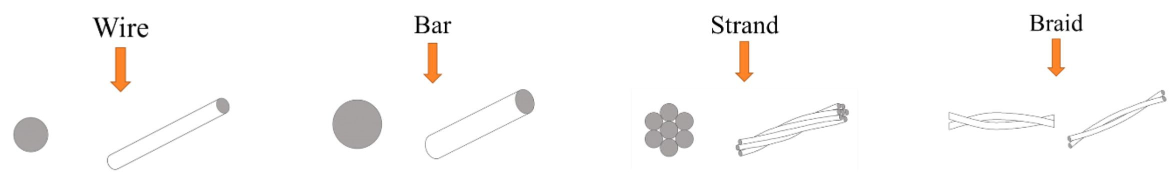

Fig. 1. Element types with prestressing steel.

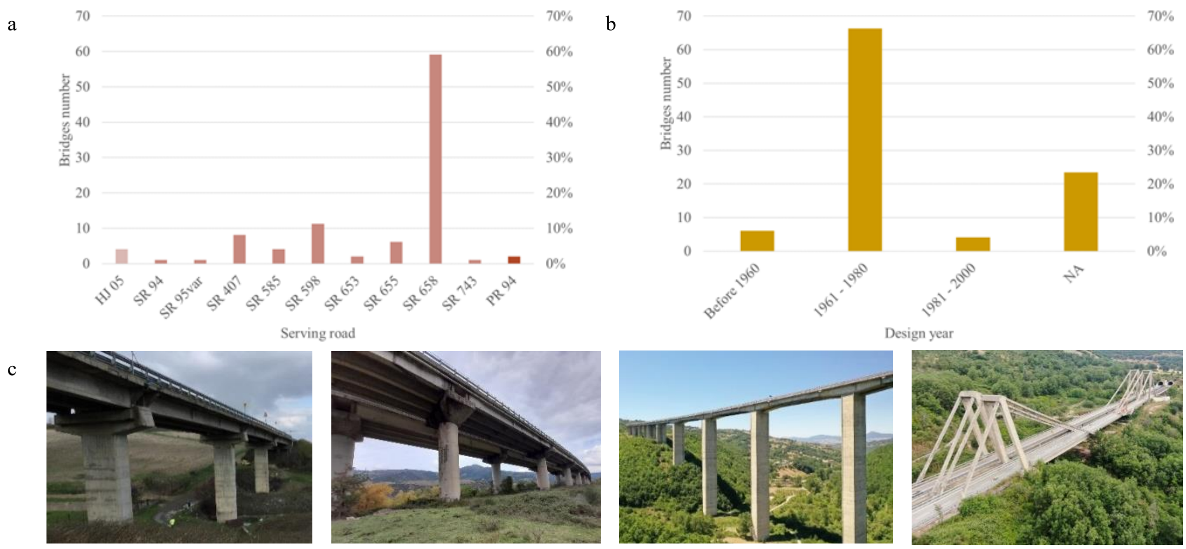

Fig. 2. (a) Bridges number for Highway Junction (HJ), State Road (SR), Provincial Road (PR); (b) bridges number for several design year ranges; (c) some case studies considered.

3. Database construction

The aim of the work is to create a database of materials mechanical properties storing data belonging to existing RC bridges having PCBs. To this scope, a territorial case study is considered, located in the Basilicata region in south of Italy. In total no. 98 bridges serving no. 1 Highway Junction (HJ – no. 4 bridges), no. 9 State Roads (SRs – no. 92 bridges) and no. 1 Provincial Road (PR – no. 2 bridges) are analysed, both pre- and post-tensioned and realized between 1960 and 2000. Fig. 2a reports the bridges number along the roads considered, while Fig. 2b shows the bridges number distributed for several design years intervals. In this case, the sample of bridges considered results mainly designed between 1961 and 1980 (66%) according to Circular of Ministry of Public Works 14/02/1962 no. 384 (M.P.W., 1962). Moreover, there is a not-negligible bridges percentage with a Not Available (NA) design year. As overview, Fig. 2c reports images of some bridges examined.

With reference to the beam material, 83% (no. 81 bridges) of the sample is composed of Prestressed Concrete Beams (PCBs), of which 73% (no. 72 bridges) is post-tensioned and the remaining 9% (no. 9 bridges) is pre-tensioned. While, 7% of the database (no. 7 bridges) is made of Reinforced Concrete (RC) bridges. Moreover, 10% (no. 10 bridges) is made of more than one construction material such as steel and RC associated with prestressed concrete.

Details of reinforcing bars steel, concrete, and prestressing steel (applied for pre- and post-tensioned elements) are collected from: original design documentation (such as drawings and reports); acceptance certificates of mechanical values measured during structure execution; in-situ tests recently performed. Materials data referred to recent structural interventions (e.g. due to repairing or maintenance), if available, are not reported into the database. Also, data are stored according to the main bridge structural element (such as beams, cross-beams, slabs, piers, pier caps, abutments). Currently, the database obtained consists, in total, of no. 188 records having a set of columns (fields) in which the following information may be found: serving road, construction year, standards reference, structural elements. For steel of reinforcing bars information archived are: steel type (smooth or ribbed bars), data source (nominal design value, acceptance certificates, or in-situ tests), bar shape (square or circular), bar diameter/side, yielding strength (f_y), tensile strength (f_u) and the ultimate elongation (A_{gt}). As for concrete: data source, cube side or cylinder dimensions, compressive strength (R_c or f_c). Finally, for prestressing steel database reports: data source, specimen type (wire, strand, bar, dywidag bar, etc.), tensile strength (f_{ptk}), strength at 0.1% of residual deformation [$f_{p(0,1)k}$], strength at 0.2% [$f_{p(0,2)k}$] of residual deformation, strength at 1% of total deformation [$f_{p(1)k}$], elongation at the maximum strength (A_{gt}) and the maximum allowable stress (σ_s).

4. First Results

In the following, starting from the information archived into the database some preliminary results are shown. In particular, strength classes percentages for steel of reinforcing bars, concrete and prestressing steel are plotted and commented. It should be noted that all percentages reported are calculated by referring to the records number available in each records sample considered. Moreover, for brevity only results related to beams, cross-beams and piers are herein shown. However, it has been observed that for many bridges data available for all structural elements are not complete.

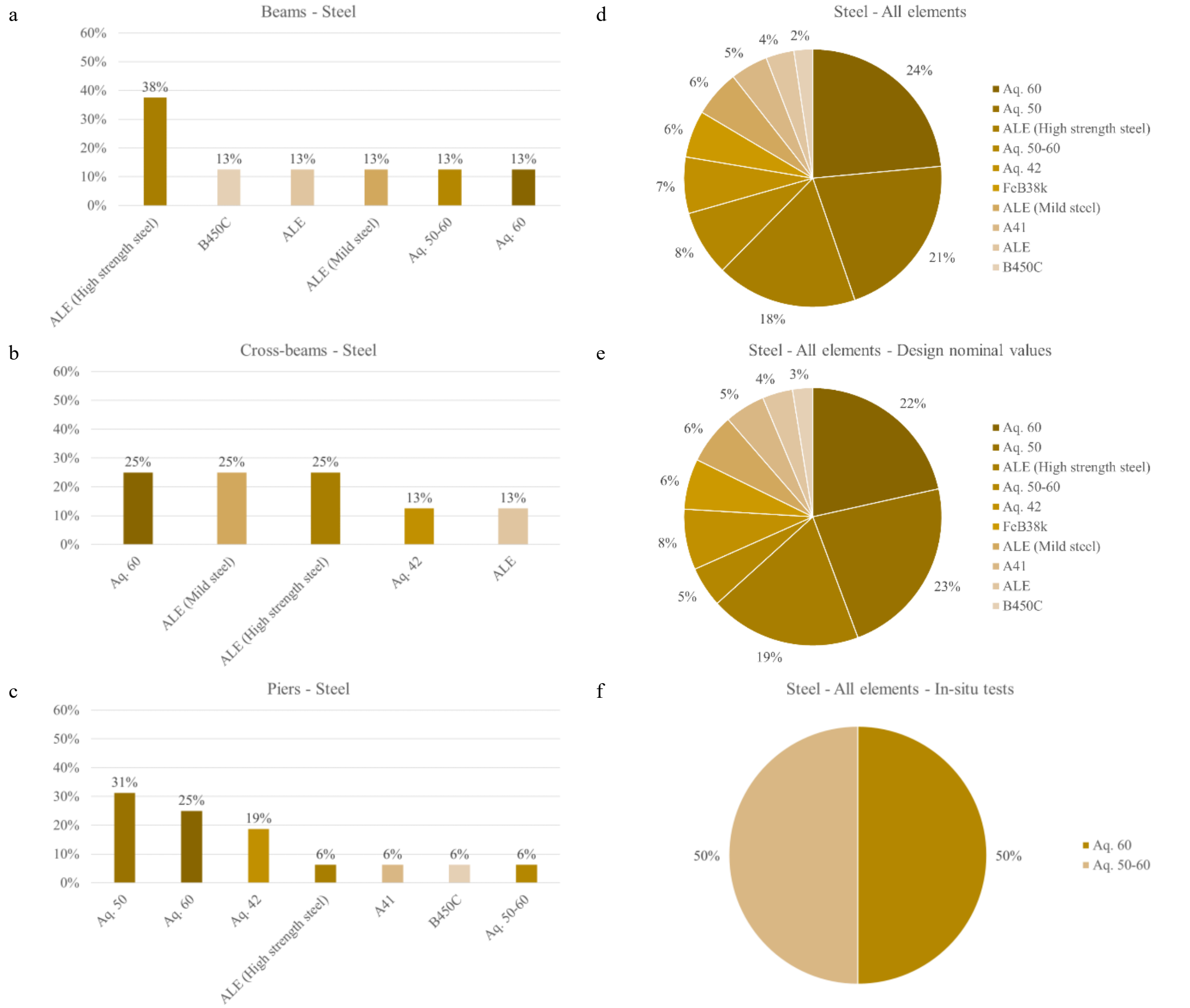

Fig. 3. Steel classes breakdown obtained for: (a) beams; (b) cross-beams; (c) piers; (d) all structural elements; (e) all structural elements, only design nominal values; (f) all structural elements, only in-situ tests.

4.1. Reinforcing steel

A sample of no. 85 records referred to reinforcing steel of all structural elements is herein examined. It is composed by 93% of design nominal values (no. 79 records), and by 7% of values obtained from in-situ tests (no. 6 records, conducted within recent experimental campaigns).

Fig. 3 reports in the histogram form the steel classes percentages for beams, cross-beams and piers. As regards the beams (n. 8 records), the following reinforcing steel classes with the related percentage are found (Fig. 3a): ALE (high strength steel) class with 38% (f_y=431 MPa), followed by B450C class (f_y=450 MPa) (13%). Whereas, for cross-beams (no. 8 records) Aq. 60 (f_y= 304 MPa) results with 25% (Fig. 3b). Finally, for piers Aq. 50 (f_y= 265 MPa) has a 31% of frequency (no. 16 records, Fig. 3c), followed by Aq. 60 (f_y=304 MPa) with 25%.

As for all structural elements, classes percentages obtained are depicted in Fig. 3d. Again, it can be noted that Aq. 60 is the most frequent class, representing 24% of the sample considered, followed by Aq. 50 (21%), and ALE (high strength steel, 18%. While, a further partitioning between design nominal values and in-situ tests is reported in Fig. 3e and Fig. 3f. In particular, the Fig. 3e confirms Aq. 50 (23%) and Aq. 60 (22%) as the most frequent steel classes within the database to date obtained. As regards the in-situ test results (Fig. 3f) few data are available, resulting consistent with Aq. 60 (50%) and Aq. 50-60 (50%).

4.2. Concrete

Within the database to date obtained a sample consisting of total 59 records referred to concrete is obtained (including all structural elements), where source data are design nominal values (85%, no. 50 records) and in-situ tests (15%, no. 9 records, conducted within recent experimental campaigns).

As results from Fig. 4a and Fig. 4b, for beams (no. 7 records) and cross-beams (no. 6 records) the concrete class R450 (compressive strength of R_c=450 kg/cm^2) has the highest presence percentage. In detail, it results 29% and 50% for beams and cross-beams, respectively. Whereas, for piers (no. 13 records) the concrete class R350 (R_c=350 kg/cm^2) has the highest percentage. Note that R350 and R450 are concrete classes used before the M.D. 1972 (Fig. 4c).

By considering all structural elements, concrete classes percentages are depicted in Fig. 4d. In this case R250 (R_c=250 kg/cm^2) results the most frequent class with 37%, followed by R350 class (24%), and R450 class (14%). A further partitioning between design nominal values and in-situ tests is reported in Fig. 4e and Fig. 4f, respectively. In particular, the Fig 4e confirms R250 (44%), R350 (22%) and R450 (16%) as the most frequent concrete classes. While, as for the in-situ tests of Fig. 4f few data are available. The values obtained are consistent with R425 class (44%), R350 class (33%), and R720 class (22%).

4.3. Prestressing steel

As for prestressing steel a sample consisting of total no. 44 records (including only beams and cross-beams) is obtained, with 68% of data collected from design nominal values (no. 30 records), and 32% from in-situ tests (no. 14 records, conducted within recent experimental campaigns through detensioning, that is to say a method for releasing the force in a tensioned wire).

Fig. 5 illustrates the percentages of prestressing steel elements into the database, as reported in the available documents. As for beams (no. 30 records), Fig. 5a indicates that prestressing is realized with: strand (37%) having a design nominal value of tensile strength f_{ptk}=1860 MPa, cable having 24/32 wires (27%), Freyssinet Bars (13%), and cable where wires number is Not Available (13%). Whereas, for cross-beams (Fig. 5b, no. 10 records) prestressing is provided by strands (40%) with a design nominal value of tensile strength f_{ptk}=1860 MPa, and by Dywidag bars (30%) having f_{ptk}=1050 MPa. As regards a sample including both beams and cross-beams, prestressing element percentages are plotted in Fig. 5c. It can be noted that strand represents the most frequent element for prestressing, with a percentage of 43%. Whereas, Fig. 5d and Fig. 5e show the results obtained by partitioning this sample between design nominal values (no. 30 records) and in-situ tests (no. 14 records). In particular, the Fig. 5d confirms the strand is the most recurrent element for prestressing in the database considered. While, Fig. 5e indicates the prestressing steel elements on which in-situ detensioning tests were conducted. In this case it results that tests of detensioning were conducted on strands (14%) providing an averaged tensile acting of f_{pm}= 1824 MPa, on cable with 24/32 wires (57%)

resulting an averaged tensile acting of f_{pm}= 725 MPa, and on cables where wires number is Not Available (29 %) with f_{pm}= 590 MPa.

Fig. 4. Concrete classes breakdown obtained for: (a) beams; (b) cross-beams; (c) piers; (d) all structural elements; (e) all structural elements, only design nominal values; (f) all structural elements, only in-situ tests.

5. Conclusions

The research here discussed aims at proposing a database collecting information on mechanical properties of materials used in existing RC girder bridges with PCBs. To date, database has been created starting from a territorial case study, located in the Basilicata region, and starting from no. 98 bridges serving Highway Junctions (HJ), State Roads (SR) and Provincial Roads (PR). Some preliminary results obtained by archiving and analyzing the database have been illustrated and commented. In detail, it mainly consists of post-tensioned PCBs bridges (73%), where prestressing steel elements are strands of different typology. As for concrete and reinforcing steel, in the cases analyzed it is not possible to identify a prevalent strength class in all the elements considered (beams, cross-beams, and piers).

Database implementation is being currently in progress, considering also bridges belonging to roads of different category. In future, the database obtained will permit of proposing probability density functions of the materials useful for reliability analysis of PCBs applied into existing bridges.

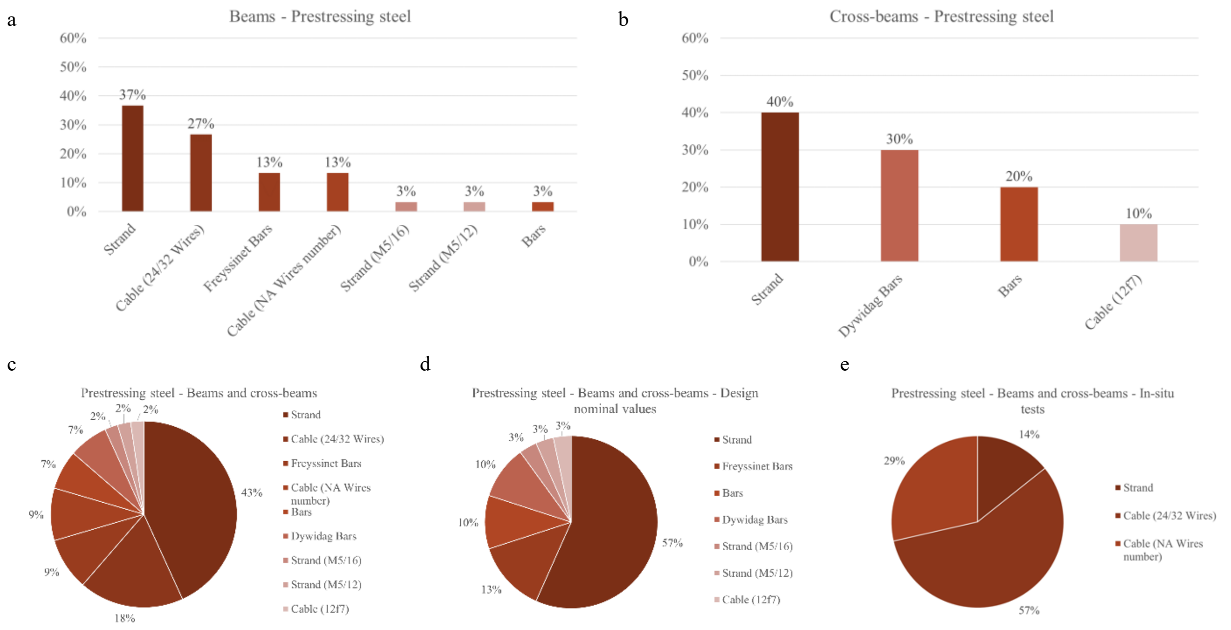

Fig. 5. Breakdown of prestressing steel elements: (a) beams; (b) cross-beams; (c) beams and cross-beams; (d) beams and cross-beams, only design nominal values; (e) beams and cross-beams, only in-situ tests.

Acknowledgements

This study was supported by FABRE – "Research consortium for the evaluation and monitoring of bridges, viaducts and other structures" (www.consorziofabre.it/en) within the activities of the FABRE-ANAS 2021-2024 research program. Any opinion expressed in the paper does not necessarily reflect the view of the funder.

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