Design of grid deck bridges with external prestressing only

Progettazione di ponti a graticcio con sola precompressione esterna

A. Devitofranceschi [1], E. Paolieri [2]

[1] *Anas SpA, Rome, Italy*

[2] *Freelance Civil Engineer, Florence, Italy*

ABSTRACT: This paper deals with the structural design of a bridge with external prestressing only, a simple and economical solution for medium span bridges. The authors consider a viaduct characterized by 45 m long spans, continuous girders, and deck made up of four post-tensioned girders with double-T section. The design of prestressing system and structural elements is carried out; the authors study with particular attention the effect of eccentric axial forces acting on girders (considering firstly both passive reinforcement and external prestressing, and secondly passive reinforcement only), and the design of anchor blocks of external prestressing cables. / Nel presente lavoro gli autori descrivono la progettazione strutturale di un ponte con sola precompressione esterna, una soluzione semplice ed economica per ponti di media luce. Si fa riferimento ad un viadotto caratterizzato da campate lunghe 45 m, schema statico di trave continua, e impalcato composto da quattro travi post-tese a doppia T. Si svolge la progettazione del sistema di precompressione e degli elementi strutturali; si studiano con particolare attenzione lo stato di pressoflessione delle travi (considerando in primo luogo sia armatura passiva sia precompressione esterna, e in secondo luogo solo armatura passiva), e la progettazione dei blocchi di ancoraggio dei cavi esterni di precompressione.

KEYWORDS: external prestressing; post-tensioning; deviator; anchor block; double-T section / precompressione esterna; post-tensione; deviatore; blocco di ancoraggio; sezione a doppia T.

1 INTRODUCTION

1.1 *Description of the bridge*

This paper proposes an extremely simple and economical solution to deal with the construction of medium span bridges using techniques that are easily available in road construction sites.

The viaduct studied is 150 m long and has 4 spans: two central spans of 45 m, and two outer spans of 30 m. The bridge is made of reinforced and prestressed concrete, and the deck is composed of four post-tensioned girders with double-T section. Girders are 43.3 m ad 28.3 m long, and are continuous at piers.

The bridge deck (Figs 1-2) has a total width of 12 m. The structural slab has a constant thickness of 0.25 m and the transverse slope is created using a layer of asphalt concrete binder with variable thickness.

Girders are produced directly inside the construction site, as they are ordinary reinforced concrete elements; external prestressing is applied before lifting girders on piers. The deck is supported by 3 piers and 2 abutments.

2 MATERIALS

Materials used are: concrete C45/55 for girders, concrete C32/40 for structural slab, steel B450C for passive reinforcement, and Dywidag threaded bars 36WR for external prestressing. Permanent corrosion protection of external prestressing bars is made of PE protection tube and grouting with cement grout after stressing.

3 LOAD ANALYSIS

Loads included in the model are:

- Permanent actions: structural and non-structural permanent loads;
- Impressed deformations: creep and shrinkage (automatically taken into account by MIDAS Civil), thermal actions ($\Delta T_{N,con}$ = 23°C, $\Delta T_{N,exp}$ = 29°C, $\Delta T_{M,heat} = \Delta T_{M,cool}$ = 7°C);
- Live loads (according to italian NTC 2018);
- Wind load (wind pressure p = 1.82 kN/m^2);
- Prestressing load (4 threaded bars 36WR Dywidag for each girder, A = 1018 mm^2, f_{jack} = 840 MPa).

4 MODELLING

4.1 *Description of the model*

Time dependent material properties (creep, shrinkage and the variation of modulus of elasticity with time) are automatically applied by MIDAS Civil to concrete. Girders, slab, and transverse diaphragms are modelled using beam elements. The bridge deck is composed of 4 girders in longitudinal X direction (including longitudinal structural slab) and structural slab in transverse Y direction.

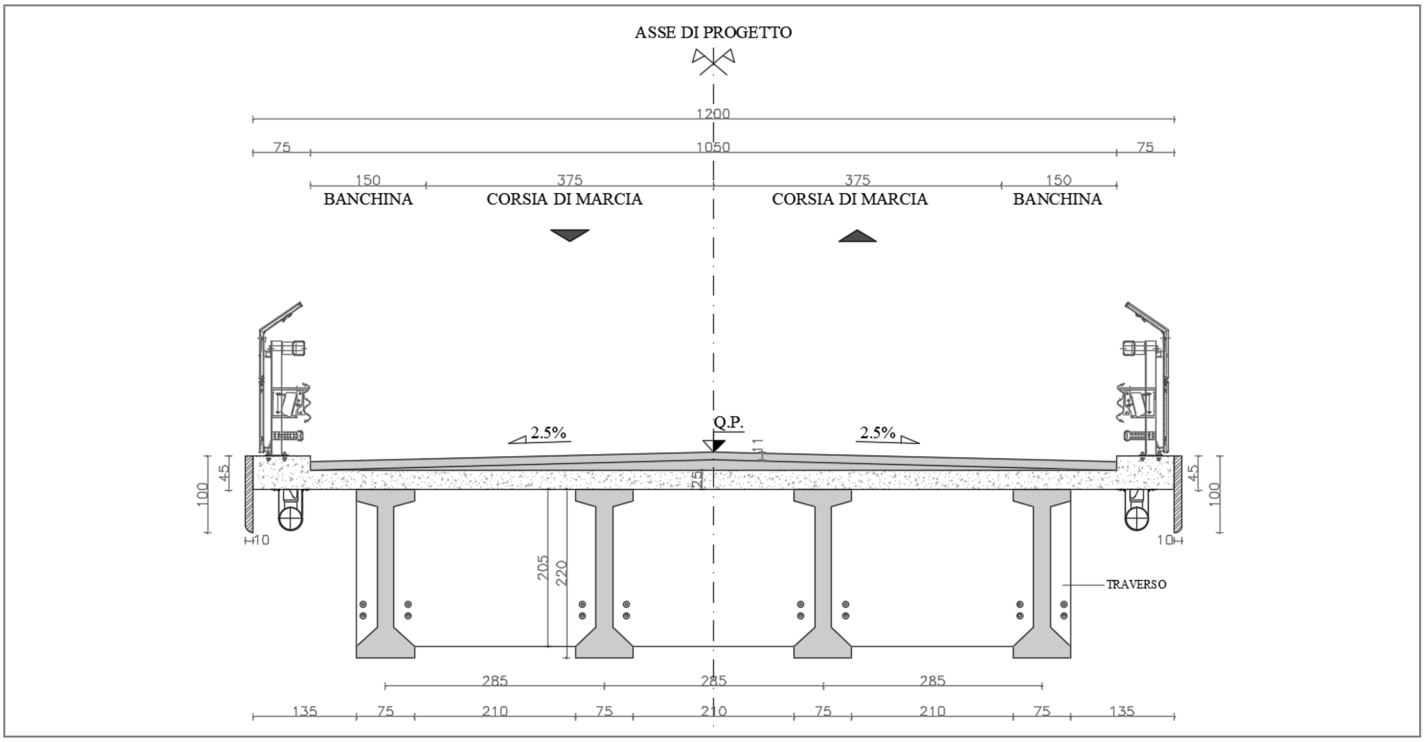

Figure 1. Bridge deck: cross section at mid span / Impalcato: sezione trasversale in campata.

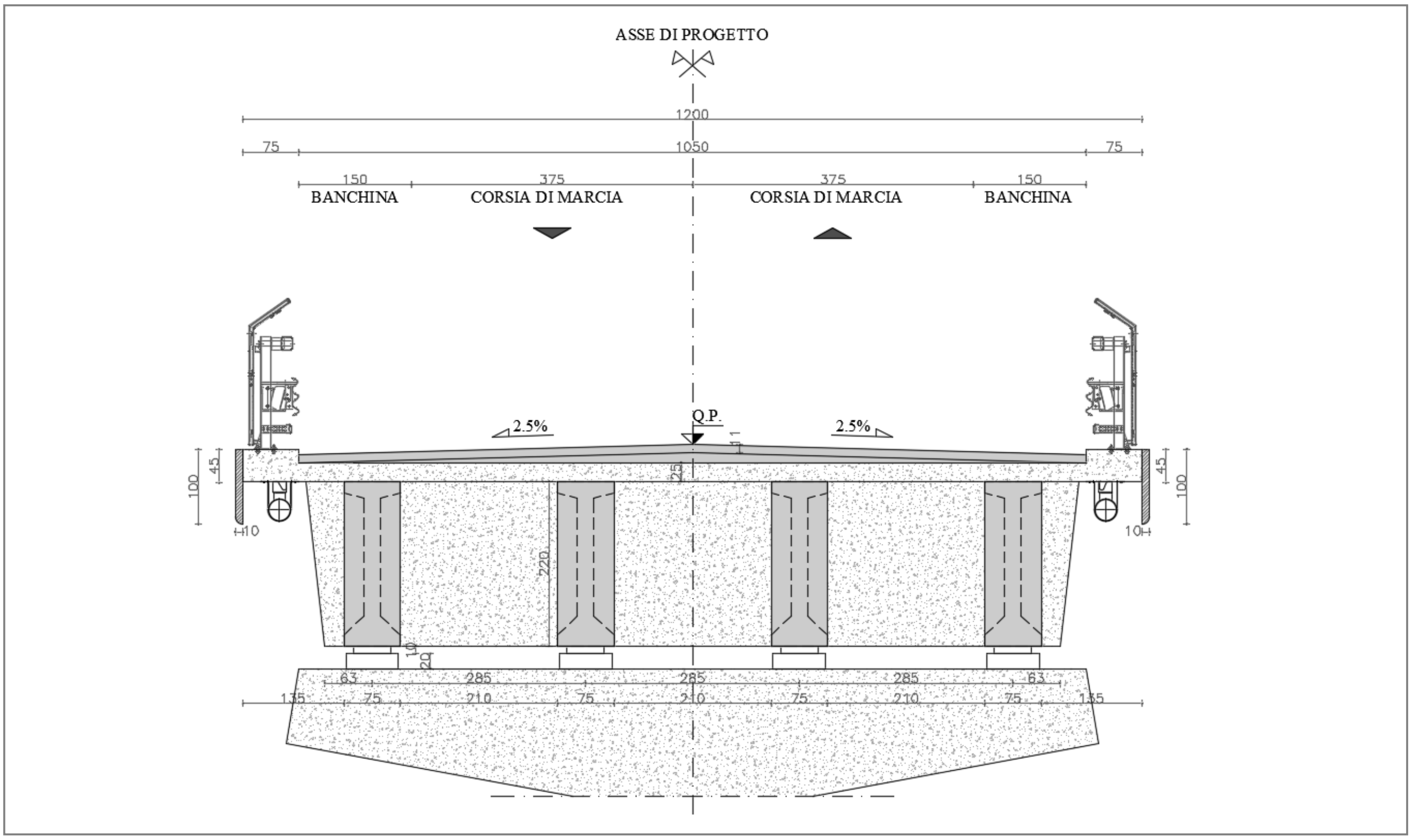

Figure 2. Bridge deck: cross section at pier / Impalcato: sezione trasversale in asse pila.

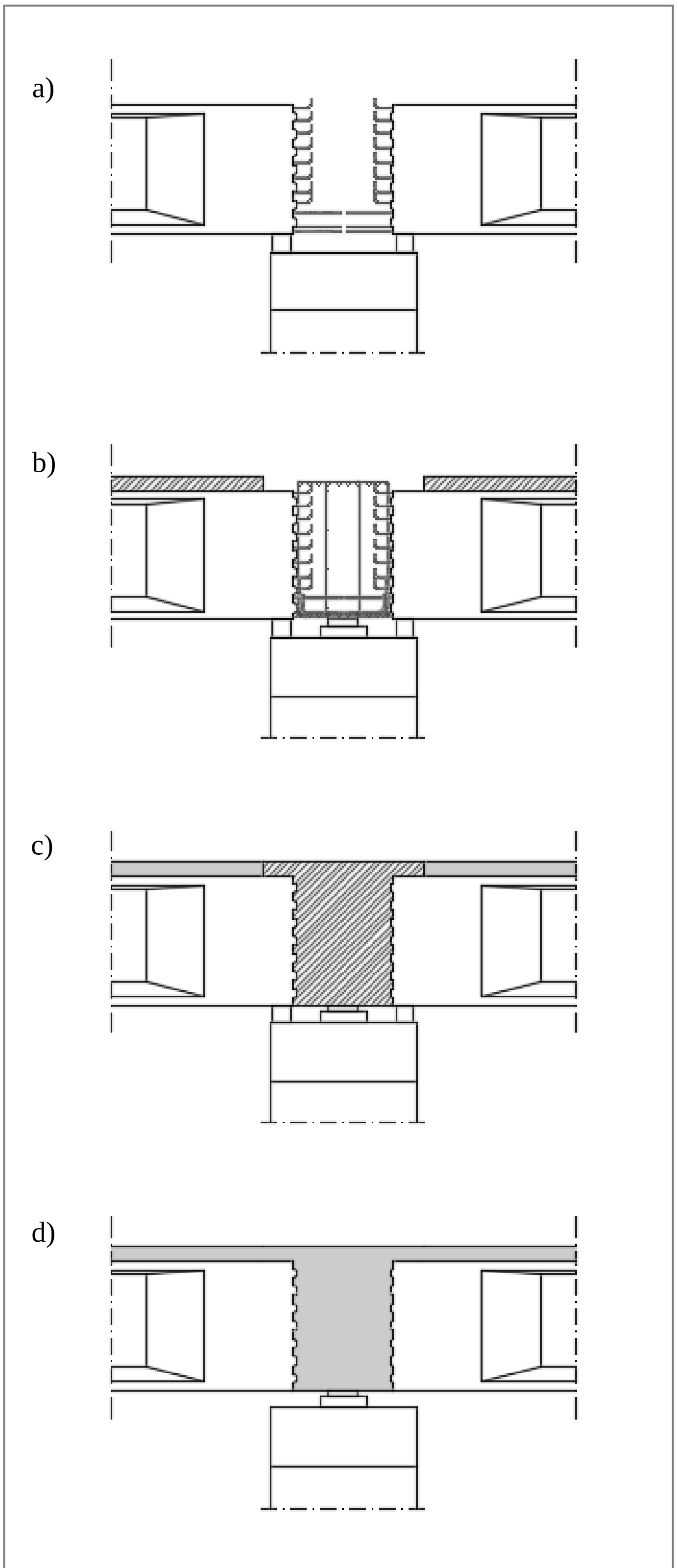

Figure 3. Construction stages: a) placement of precast girders over temporary supports located on pier heads and abutments, b) placement of slab's reinforcement and casting of deck slab, and placement of pier transverse diaphragm's reinforcement, c) realisation of pier transverse diaphragm, d) removing of temporary supports / Costruzione per fasi: a) posizionamento delle travi prefabbricate su appoggi temporanei ubicati sulle pile e sulle spalle, b) posizionamento dell'armatura della soletta e getto della soletta, e posizionamento dell'armatura del traverso di pila, c) realizzazione del traverso di pila, d) rimozione dei supporti temporanei.

The transverse structural slab allows the collaboration between longitudinal girders. Each beam in longitudinal direction represents the precast girder and the collaborating structural slab.

Girders are continuous and simply supported on piers. The structural continuity is obtained through the realisation of pier transverse diaphragms after the placement of precast girders over temporary supports.

The numerical model also takes into account construction stages (Fig. 3): application of external prestressing to girders; lifting of girders; realisation of bridge deck and continuity on piers. The study takes into account the change both in girders' section and in girders' boundaries.

The external prestressing is applied to the precast girder through 4 threaded bars, 2 on each side of the structural element (Figs 4-5).

5 DESIGN OF STRUCTURAL ELEMENTS – ULS AND SLS

5.1 *Design of girder*

Maximum values of bending moment (ULS) for girder are:

$M^{+}_{ed,ULS}$ = + 13100 kNm (at mid span)

$M^{-}_{ed,ULS}$ = - 21770 kNm (at central support)

On the other hand, values of moment resistance are:

M^{+}_{rd} ($N_{ed,ULS}$ = - 4110 kN) = + 15600 kNm

M^{-}_{rd} ($N_{ed,ULS}$ = 0) = - 23900 kNm

Maximum value of shear force (ULS) for girder is:

$V_{ed,ULS}$ = 3100 kN

while shear resistance is equal to:

V_{rd} = 3530 kN

Furthermore, additional longitudinal reinforcement is provided to transfer the prestressing load from the anchorage to the girder (positions 8 and 9 in Figure 4).

Figures 4-7 show reinforcement details of girder.

Crack control at SLS is also carried out. For girder section at mid span the following values are obtained:

$\sigma_{c,ra}$ = 9 MPa < 19.2 MPa

$\sigma_{c,pe}$ = 5 MPa < 14.4 MPa

$\sigma_{s,ra}$ = 170 MPa < 313 MPa

$w_{d,fr}$ = 0.2 mm < 0.3 mm

$w_{d,pe}$ = 0.04 mm < 0.2 mm

On the other hand, for girder section at central support the following values are obtained:

$\sigma_{c,ra}$ = 18 MPa < 27 MPa

$\sigma_{c,pe}$ = 13 MPa < 20.25 MPa

$\sigma_{s,ra}$ = 279 MPa < 313 MPa

$w_{d,fr}$ = 0.3 mm < 0.4 mm

$w_{d,pe}$ = 0.2 mm < 0.3 mm

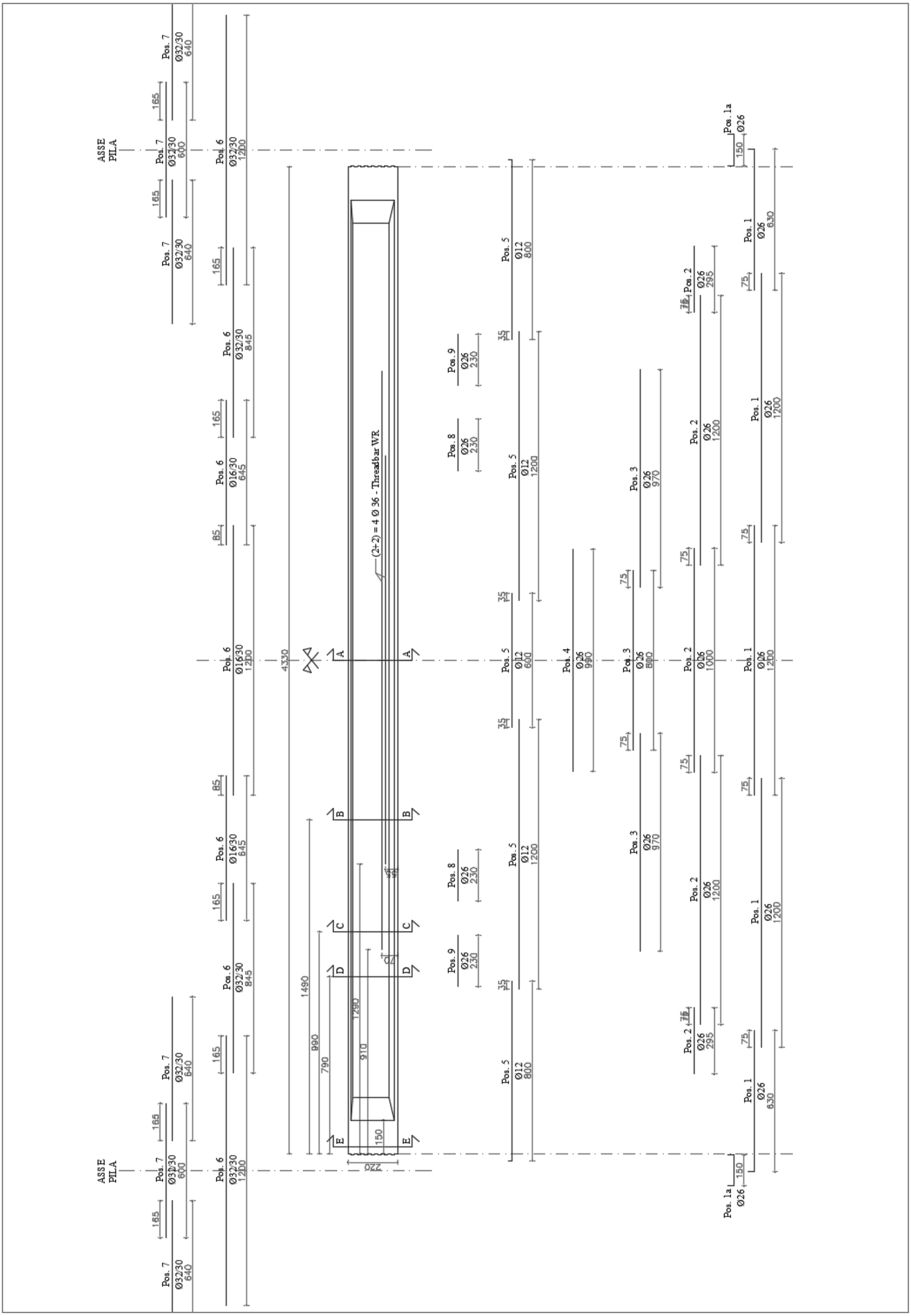

Figure 4. Girder: longitudinal reinforcement / Trave: armatura longitudinale.

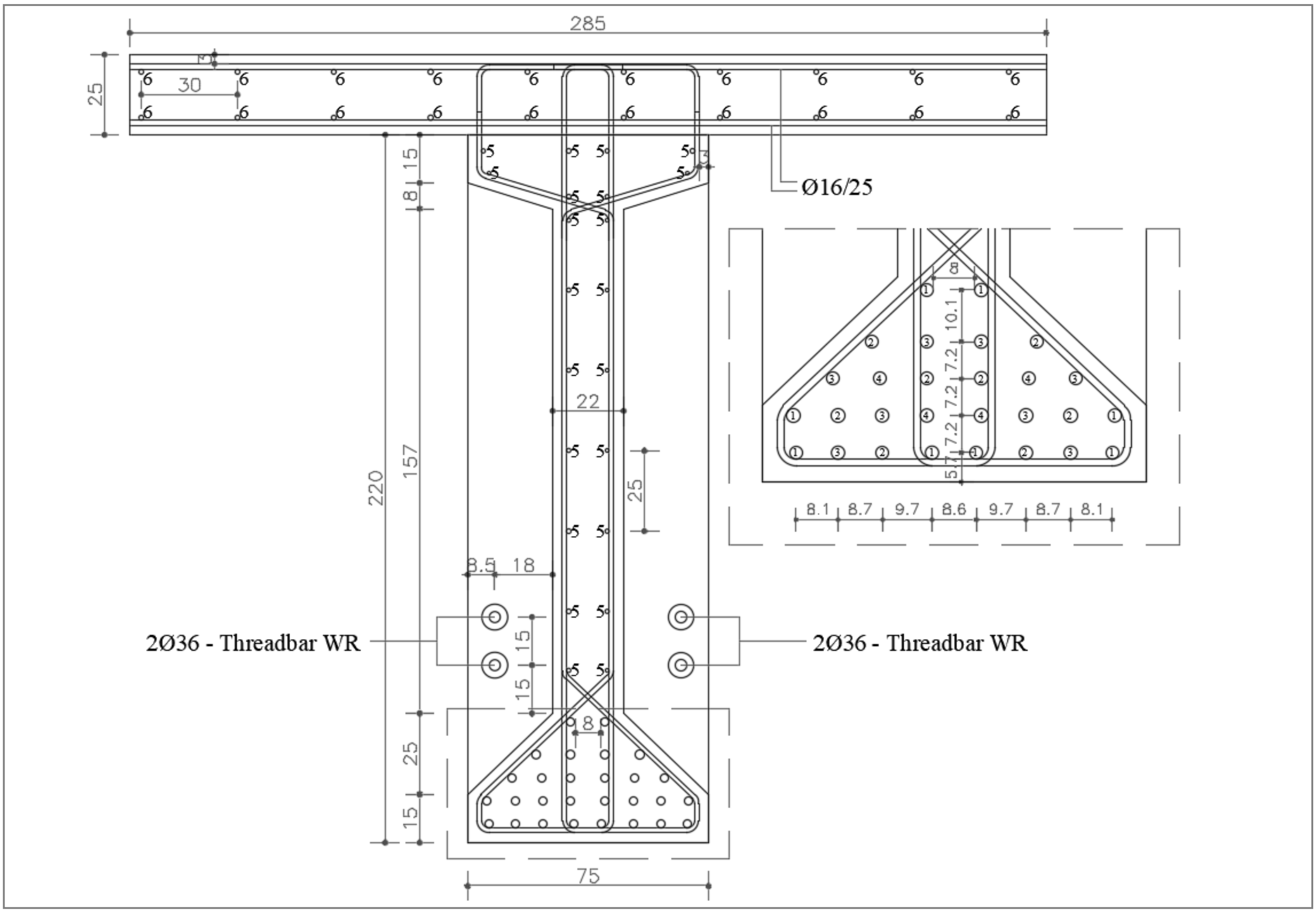

Figure 5. Girder: section A-A / Trave: sezione A-A.

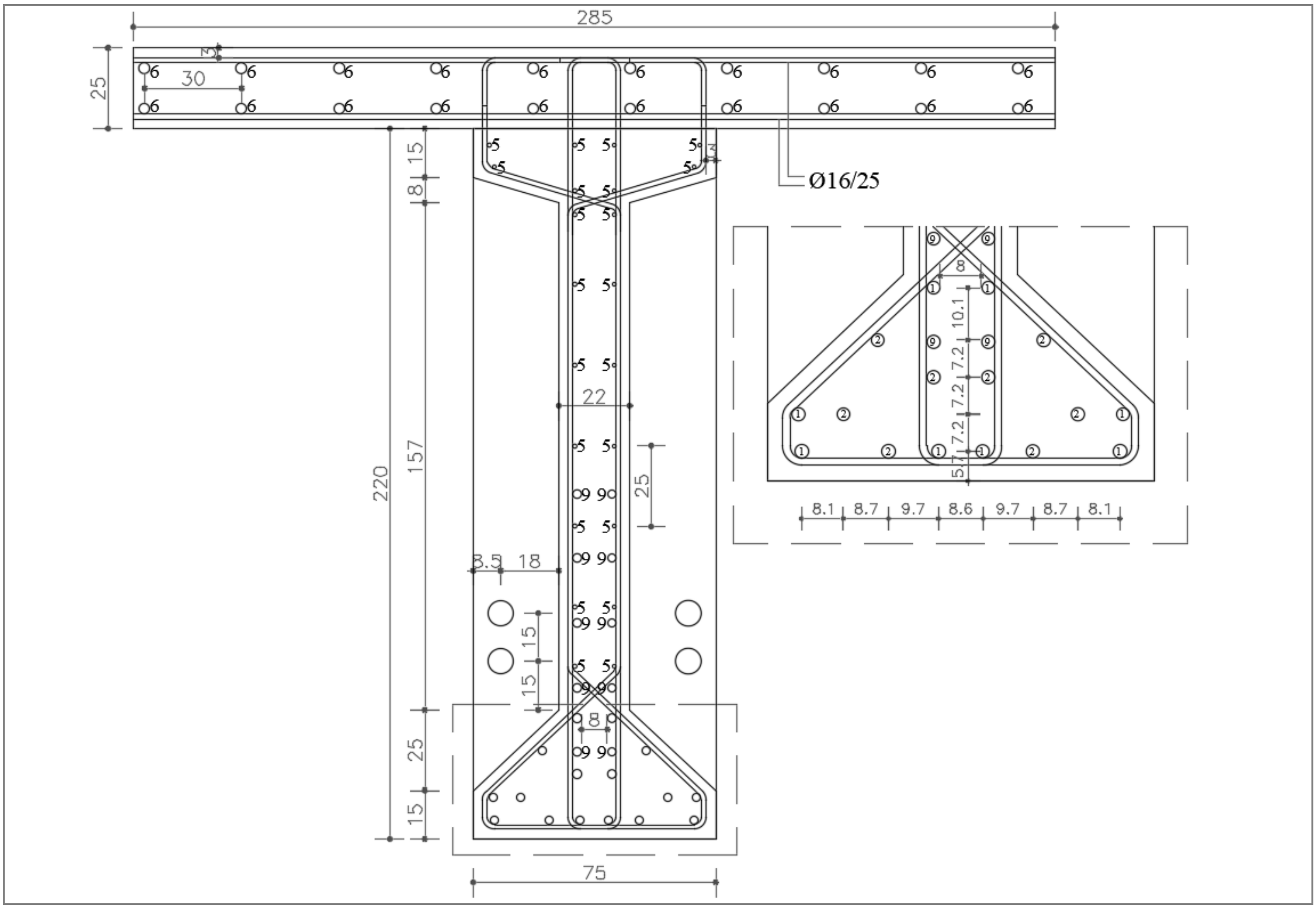

Figure 6. Girder: section D-D / Trave: sezione D-D.

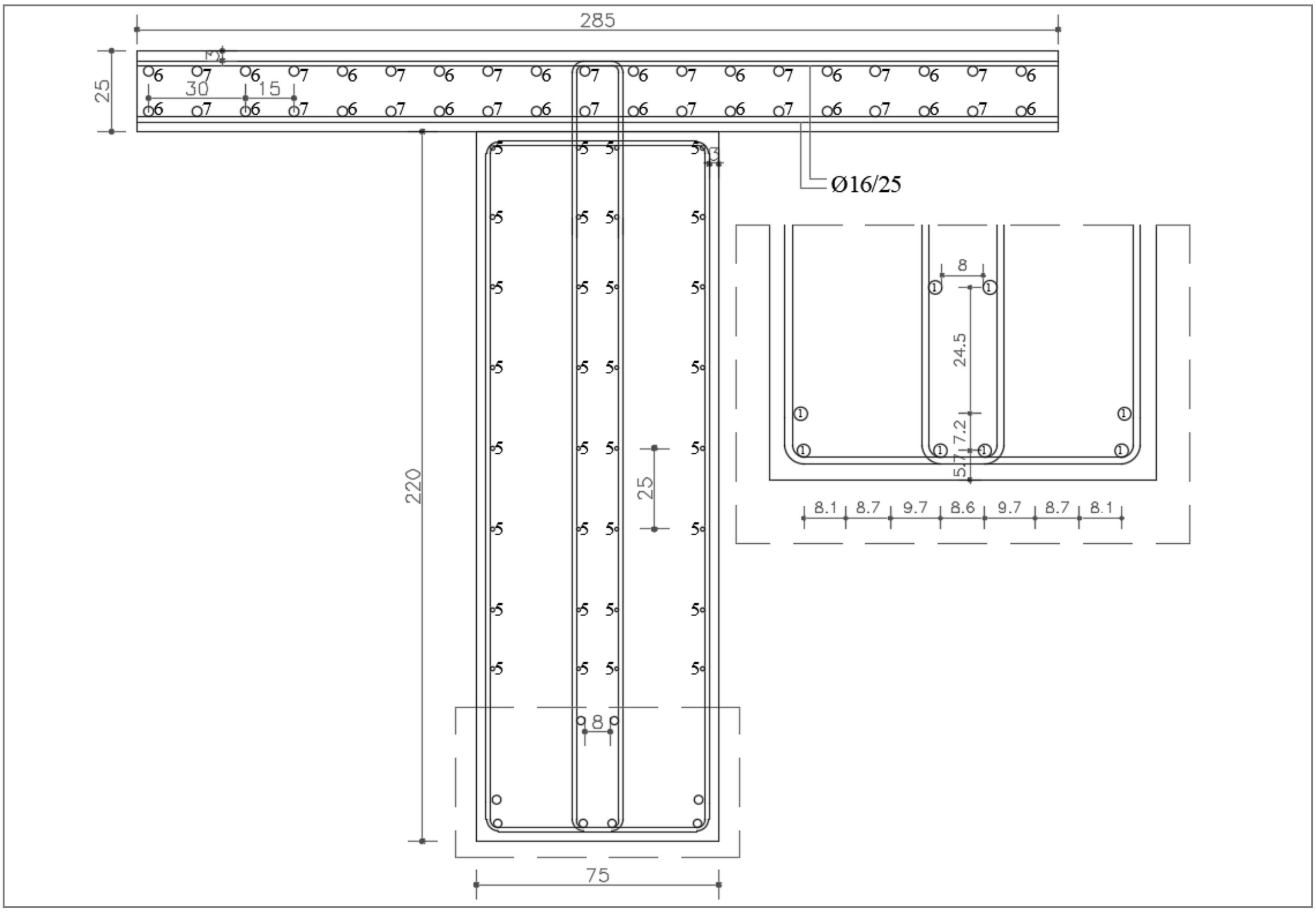

Figure 7. Girder: section E-E / Trave: sezione E-E.

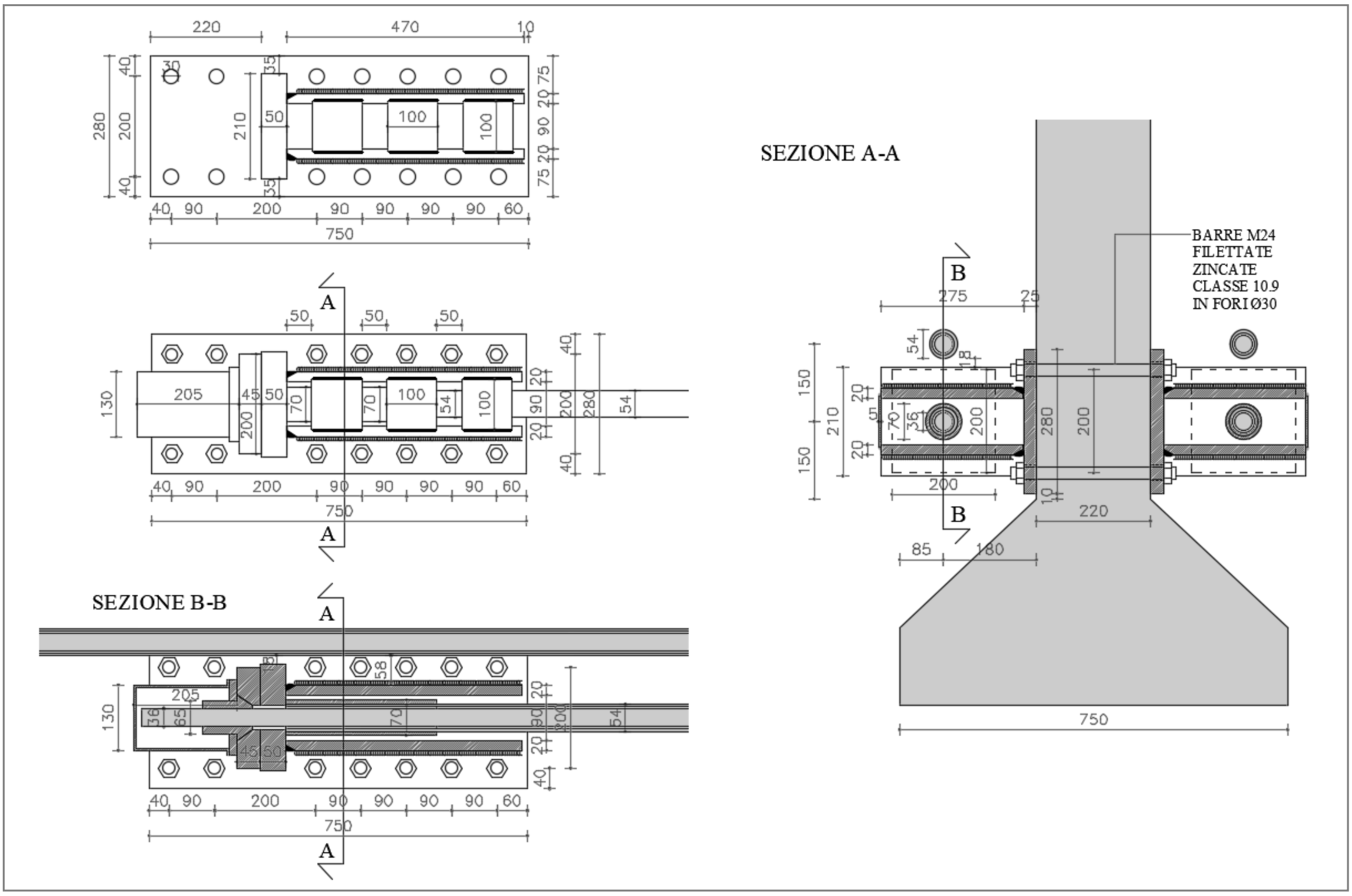

Figure 8. External prestressing bars' anchorage / Ancoraggio della barra di precompressione esterna.

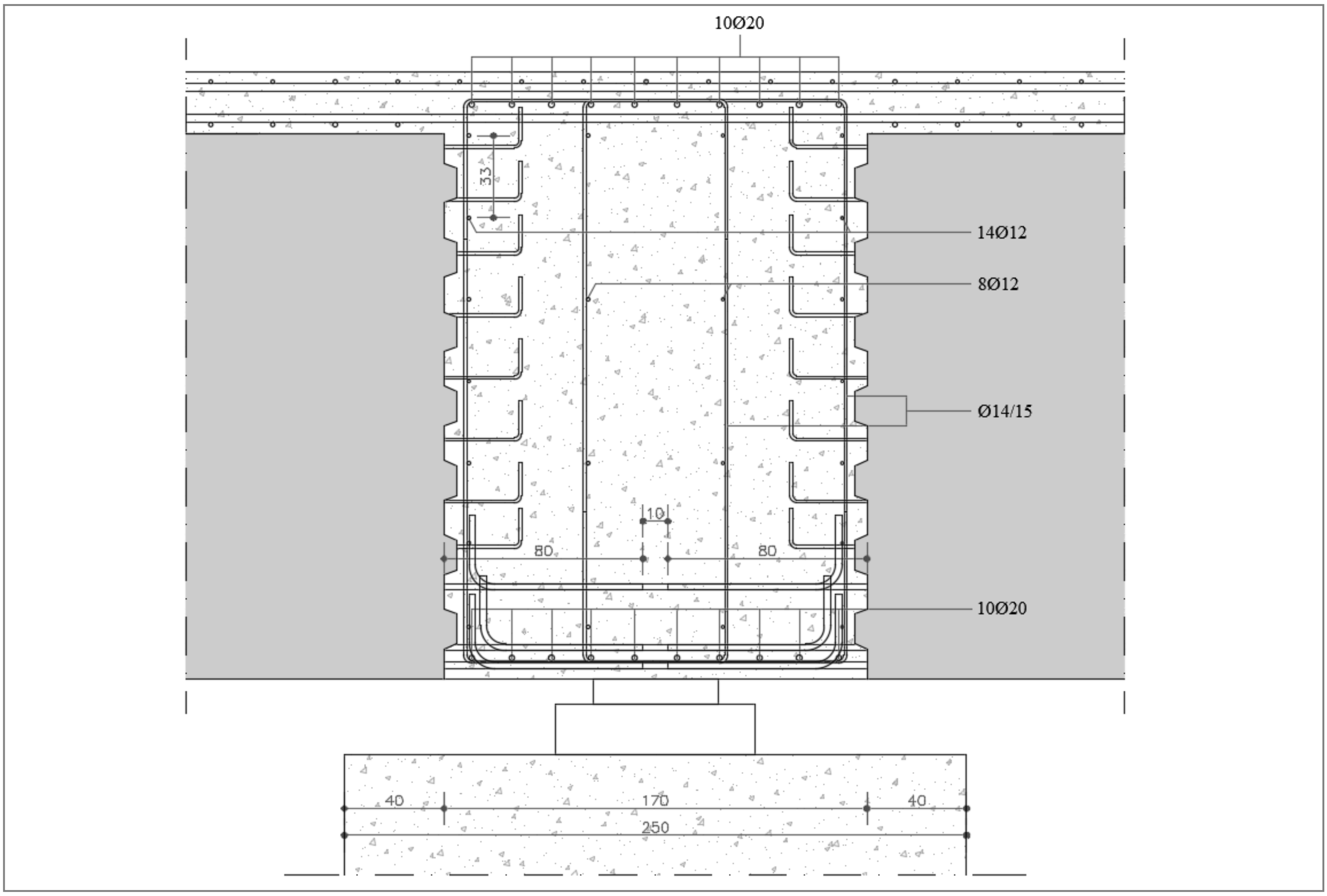

Figure 9. Node at pier / Nodo in asse pila.

5.2 *Design of prestressing bars' anchorage*

Each external prestressing bar is anchored to the girder by a system of steel plates (Fig. 8).

To fix the anchorage to the girder, 14 threaded and galvanized bars are used:

d_{bar} = 24 mm
F_d = 1028 kN
$F_{s,rd}$ = 1218 kN

5.3 *Design of node at pier*

Figure 9 shows the node at pier.
Particular attention has to be paid to the bottom bars (position 1 in Figures 7, 4), which are usually compressed, but can exert tension for strong seismic condition or under a particular combination where friction of support is the dominant action. In the proposed deck they consist in 8Φ26 per girder. Their size and quantity have been calculated in order to ensure adequate ductility as per EC2 part 2 point 6.2.(110).(iii). Overlapping of position 1 is ensured by position 1a (Figs 4, 9).

6 QUANTITIES

The main quantities characterizing the studied viaduct are:

- Total length of the bridge: 150 m
- Length of the main span: 45 m
- Bridge width: 12 m
- Road width: 10.5 m
- Maximum lifting weight: 1027 kN
- Longitudinal prestressing: 700 kg of prestressing threaded bars for each girder
- Reinforcement bars for girder: 233 kg/m
- Reinforcement bars for slab: 61 kg/m^2

7 FINAL REMARKS

The proposed deck is a simple, reliable and economical structure available to cope with mid range deck span, that can be directly produced on site.

The prestressing system can be inspected with minimum effort and eventually replaced even under traffic condition.

L'impalcato proposto è una struttura semplice, affidabile ed economica in grado di superare campate di media lunghezza, e può essere realizzato direttamente in cantiere.

Il sistema di precompressione può essere ispezionato agevolmente ed eventualmente sostituito anche in condizioni di traffico aperto.

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