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# Replacement of the Deck and Rehabilitation of the Viaduct at the Link Between M-40 and M-607 in Madrid (Spain)

## *Sustitución del tablero y rehabilitación del viaducto del enlace entre la M-40 y la M-607 en Madrid (España)*

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**ABSTRACT**

The existing concrete viaduct 560 m long at the link between M-40 ring road and M-607 expressway in Madrid (Spain) was subjected to a very comprehensive process of evaluation and testing after high deck deflections and surface cracking were detected. As conclusion of these studies very severe damages and a process of concrete degradations were confirmed which led to the decision of dismounting the existing deck structure and constructing a new one supported on the existing substructure which had to be repaired and reinforced. Grupo Puentes has carried out both the process of deck disassembly and the construction of the new deck in a record time of approximately nine months. The viaduct is in a very traffic congested link to approach Madrid and crosses over not only the main roads, M-40 ring road and M-607 expressway, but also two approach ramps and two railway lines, one of them high-speed line.

KEYWORDS: viaduct, rehabilitation, precast, concrete, disassembly.



**RESUMEN**

El viaducto de hormigón existente en el enlace entre la carretera de circunvalación M-40 y la vía rápida M-607 en Madrid (España), con 560 m de longitud, fue sometido a un proceso de evaluación y ensayos muy completo tras ser detectadas grandes deformaciones del tablero y fisuración superficial. Como conclusión de estos estudios se confirmaron daños severos y un proceso de degradación del hormigón que dieron lugar a la decisión de desmontar el tablero existente y construir uno nuevo aprovechando la subestructura, que tuvo que ser reparada y reforzada. Grupo Puentes ha llevado a cabo tanto el proceso de desmontaje del tablero como la construcción del nuevo en un tiempo récord de nueve meses. El viaducto se sitúa en un enlace muy congestionado de tráfico para el acceso a Madrid y cruza no solo sobre las carreteras principales, vía de circunvalación M-40 y vía rápida M-607, sino también sobre dos ramales de acceso y dos líneas ferroviarias, una de ellas de alta velocidad.

PALABRAS CLAVE: viaducto, rehabilitación, prefabricado, hormigón, desmontaje.



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## 1. EXISTING VIADUCT

### *1.1. General description*

The original viaduct located at the link between M-40 ring road and M-607 in Madrid was built in the nineties and allowed the connection of the south-ward carriageway of this last road with the north-ward carriageway of M-40 (Figure 1).

The viaduct consisted of 17 spans with span lengths of 20 + 32 + 35 + 37 + 55 + 32 + 36 + 38 + 29 + 28.5 + 36 +


Figure 1. Viaduct general location plan.

2×29 + 2×32.5 + 30 + 20 m, and a total length of 551.5 m, all dimensions referred to the curved alignment axis according to the existing definitive design (Figure 2).

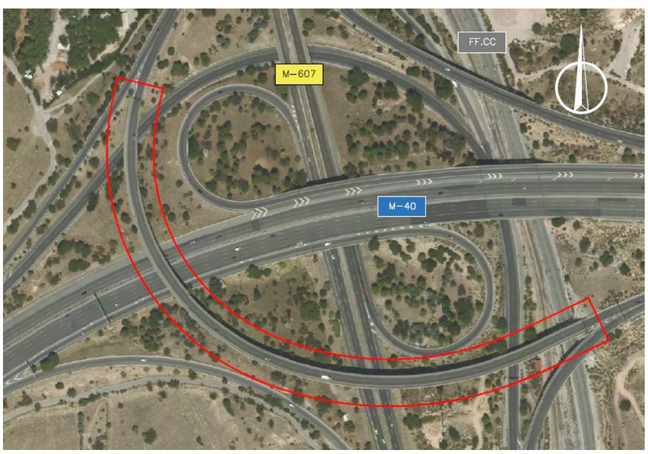



Figure 2. Existing viaduct general aerial view.

The deck cross section was a post-tensioned concrete slab with longitudinally constant depth, except at both piers adjacent to 55 m long span, and cylindrical longitudinal voids of different diameter formed by expanded polystyrene. The soffit of the section was curve with maximum depth of 1.4 m at central axis (Figure 3).

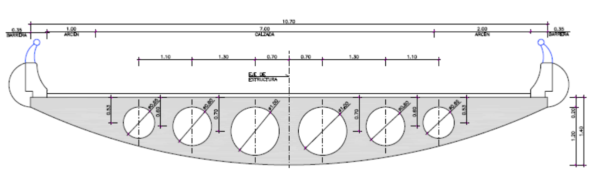


Figure 3. Existing viaduct deck typical cross section.

The piers consisted of simple shafts with ellipsoidal constant section, and they were founded by means of footings.

### 1.2. *Detected damages and actions to carry out*

Due to the high vertical deflections observed in some of the longest spans of the viaduct, it was subjected to a special inspection at the end of 2018. As conclusion of the studies and tests carried out during this inspection very severe damages were detected, with clear affection to the strength and de-formability of the concrete of the deck and its capacity to withstand the required loads [2][3].

Since no repair procedure was found economically feasible and possible to reinforce the deck, the road authority final decision was the dismantling of the deck and its replacement by a new one. The sub-structure, piers, abutments, and foundations would be kept with the necessary reinforcement actions.

## 2. DISASSEMBLY PROCESS

### 2.1. *General considerations*

All the process of dismantling the existing viaduct deck has been developed following some requirements to guarantee the safety and accuracy of all operations [4]. The following lines have guided this process:

- All deck cuts were made by means of diamond wire; in this way no demolition of aerial structures was carried out at deck position. The deck pieces were moved afterwards to the in-site demolition area.
- A detailed design was prepared, by Pondio Ingenieros, to define all operations and the exact position of each deck cut, taken into account the prestressing design, the deck sections (voided or not) and the weight of the resulting pieces [5].
- All pieces of deck were fully supported, or hanged as explained below, before beginning of cutting operations.
- The removal of deck sections was carried out by cranes of appropriate capacity.
- The removal of those deck sections located over service roads was made in the night hours.
- The traffic was kept along the different roads existing in the link and it was stopped only some hours at night when removal operations must be developed.
- Wind velocity was measured continuously to guarantee the safety conditions for cranes operations. There were some alert values to stop operations depending on each machine.

Figure 4. Temporary steel towers to support existing deck sections.

### 2.2. *Typical spans*

The process of disassembly of the typical spans of the old deck has been performed by means of cutting completely the sections with diamond wire, which has advantages from the point of view of safety and control of the structural behaviour of the bridge. The concrete barriers on both sides of the deck were cut together with the deck sections. In this way, the deck was divided in sections with variable length which, after being supported by temporary steel towers (Figure 4), were taken away by means of cranes to the demolition area (Figure 5). In this way, no demolition itself is made at the elevated deck position, not even that for concrete barriers. All products resulting from demolition, concrete and steel, was fully recycled by specialized companies.

Figure 5. Disassembly of typical span section over M-607 approach ramp.

The cutting order and the corresponding procedures have been carefully studied to ensure the stability and integrity of the structure and to avoid in all time the complete traffic cutting of the roads under the bridge.

Figure 6. Cross section view of a disassembled segment of typical span.

The typical length of the deck sections to be re-moved was 12 m with a weight of 2708 kN for voided sections (Figure 6). Nevertheless, the maximum weight of the heaviest section was 3090 kN for the section placed on pier P7 which was 12,67 m long. In turn, the longest sections with a length of 13 m had a weight of 2943 kN, corresponding to voided deck sections.

Figures 7 to 24 show the disassembly phases span by span. The green numbers over the different sections represent the order of sections removal once the cuttings have been done:

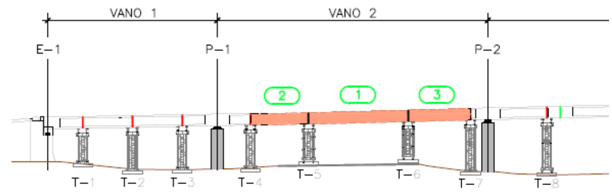



Figure 7. Phase 1: Disassembly of span 2.

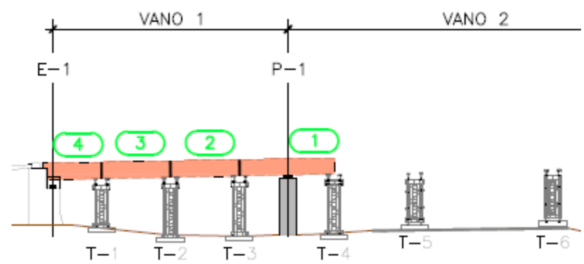



Figure 8. Phase 2: Disassembly of span 1.

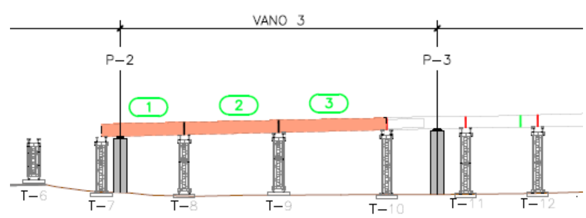
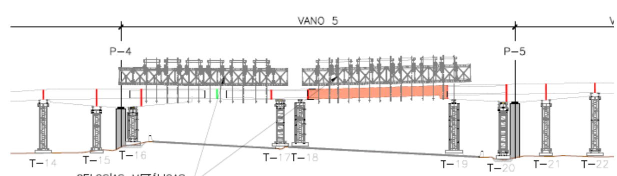
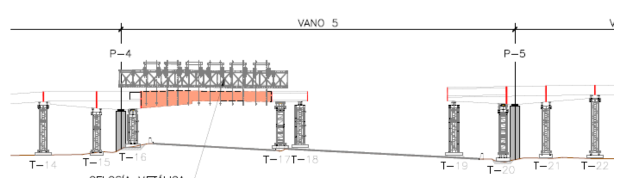
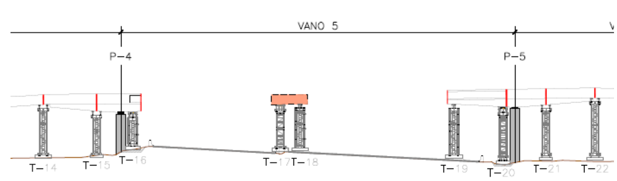



Figure 9. Phase 3: Disassembly of span 3.



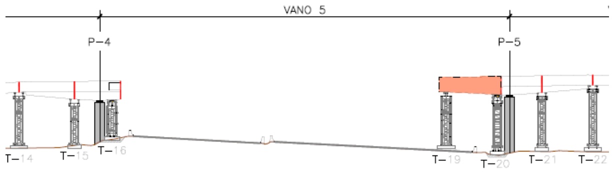



Figure 10. Phase 4: Disassembly of span 5 over M-40.

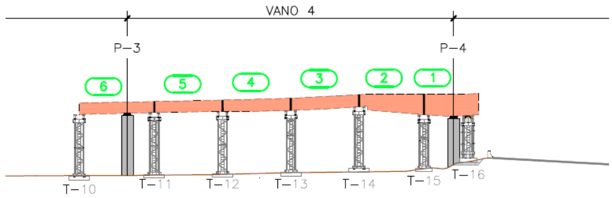



Figure 11. Phase 5: Disassembly of span 4.

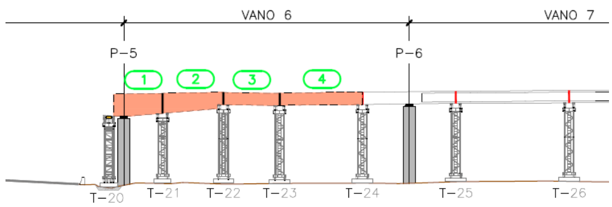



Figure 12. Phase 6: Disassembly of span 6.

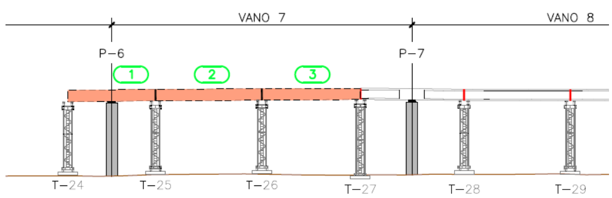



Figure 13. Phase 7: Disassembly of span 7.

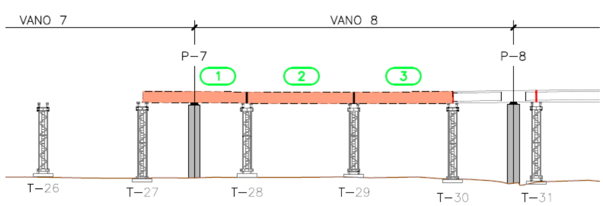



Figure 14. Phase 8: Disassembly of span 8.

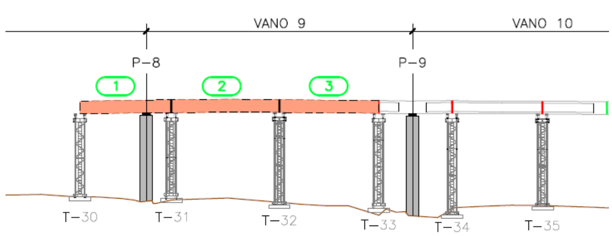



Figure 15. Phase 9: Disassembly of span 9.

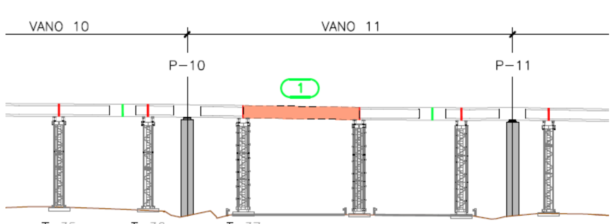



Figure 16. Phase 10: Disassembly of span 11 midspan segment over M-607.

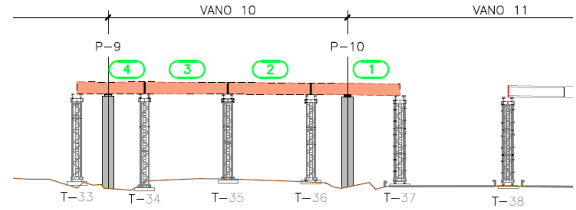



Figure 17. Phase 11: Disassembly of span 10.

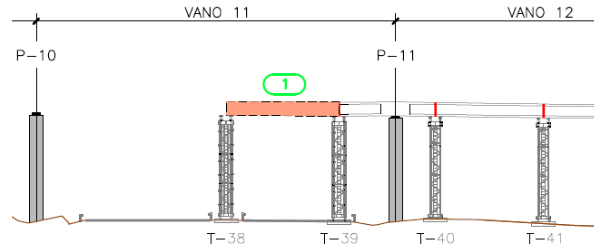



Figure 18. Phase 12: Disassembly of rest of span 11 over M-607.

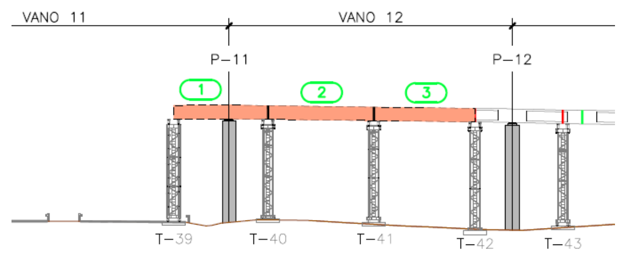



Figure 19. Phase 13: Disassembly of span 12.

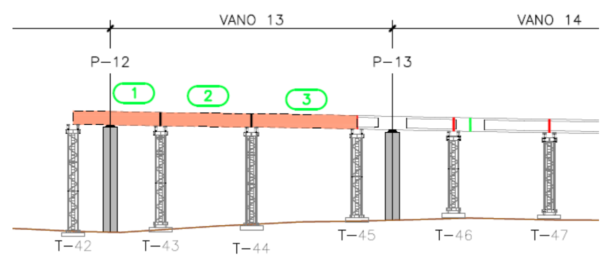



Figure 20. Phase 14: Disassembly of span 13.

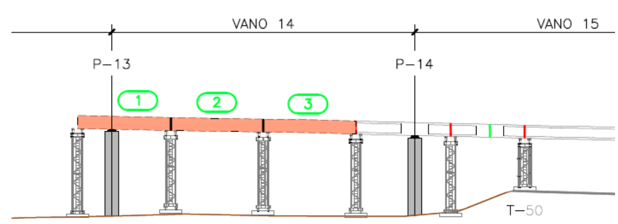



Figure 21. Phase 15: Disassembly of span 14.

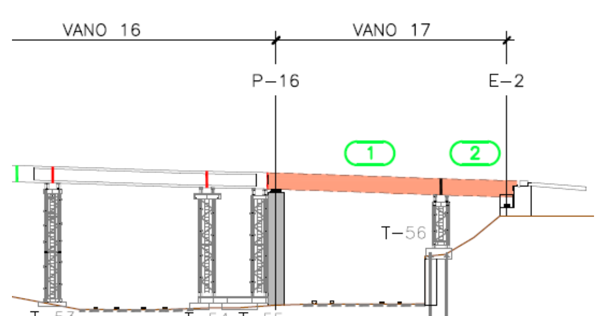



Figure 22. Phase 16: Disassembly of span 17 over railway line.

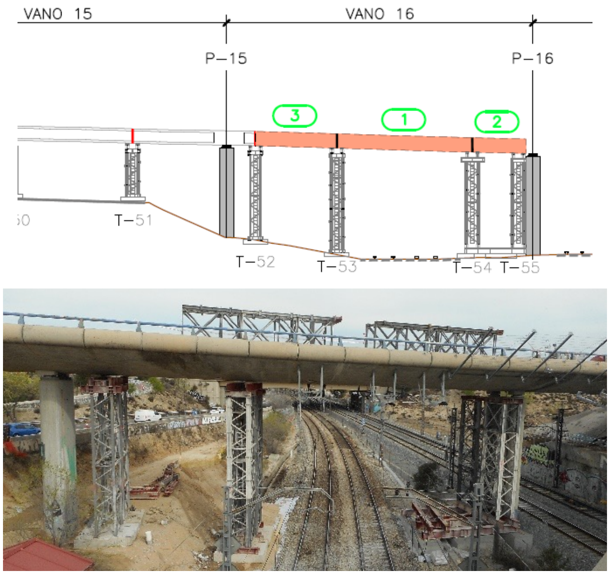


Figure 23. Phase 17: Disassembly of span 16 over railway line.

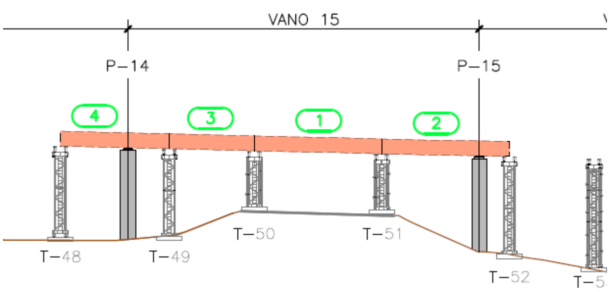


Figure 24. Phase 18: Disassembly of span 15.

At the spans over the railway lines between piers P15 and P16 and between P16 and abutment E2 (Figures 22 and 23), respectively, longest sections were needed, up to 14 m and 3414 kN, due to the presence of the railway lines, which required wider horizontal clearances between towers. For those sections additional cuts had to be performed to divide the sections into lighter parts by removing the ends of the section in first phase and then the central core in second phase (Figure 25). The three parts were tied together by means of a steel cross beam over the deck and prestressed bars (Figure 26). The sections on this area were cut and removed in close coordination with the railway administration to provide gaps without traffic of trains for these operations, always in night hours.

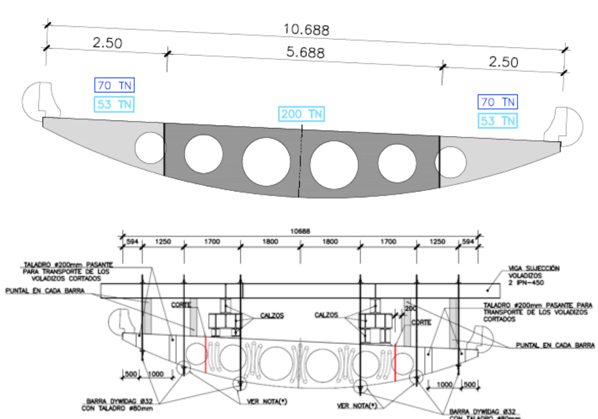


Figure 25. Deck cross section divided into three parts at spans 16 and 17 over railway lines.


Figure 26. Auxiliary steel structure to tie deck cross section over railway lines.

### 2.3. *Span over M-40 main road*

The phase of disassembly of the span over the M-40 ring road, between piers P4 and P5, was particularly difficult and hazardous due to the span length, the longest one (56.227 m), and the presence of traffic at least in one carriageway of M-40 ring road. For this spans the towers could only be placed in the road berms and in the central reserve of M-40 and, therefore, it was necessary to find out an unique way of supporting the deck sections to be cut.

This alternative method had to ensure the safety during all operations with the traffic under the deck during certain phases. It was decided to place steel trusses over the deck spanning each carriageway of the M-40 ring road (Figure 27). These trusses were supported on the deck over the existing substructure and on temporary towers placed on the berms and on the central reserve (Figure 28). The procedure consisted of dividing the span into shorter deck segments to be hanged from the trusses before been cut and allowing the removal of the different segments.

In fact, this span was divided into 14 sections (Figure 27). The central one, 5.3 m long and 1187 kN heavy, was directly supported on two steel towers placed at the central reserve of the M-40. The rest of the deck segments had different lengths ranging from 2 to 3.5 m and weights up to 961 kN. Each one of these segments were hanged from the steel trusses before cutting them, by means of four 32 mm or 36 mm diameter prestressing bars stressed to forces ranging from 147 to 245 kN; diameter chosen according to the weight of the segment. The cuts were conducted, in the same way as the rest of them, by means of diamond wire including the concrete barrier.

Once all the segments were cut and fully hanged from the trusses, they were taken by the cranes to be lowered in the vertical of their position. In this position each segment was left on a truck cage to be transported to the demolition area (Figure 30). The whole operation was conducted during the night, cutting only the traffic on one of the carriageways of the M-40 each time. In this way, to dismantle the complete span two nights were required. All the operations were finished with success, without any incident, as they had been planned.

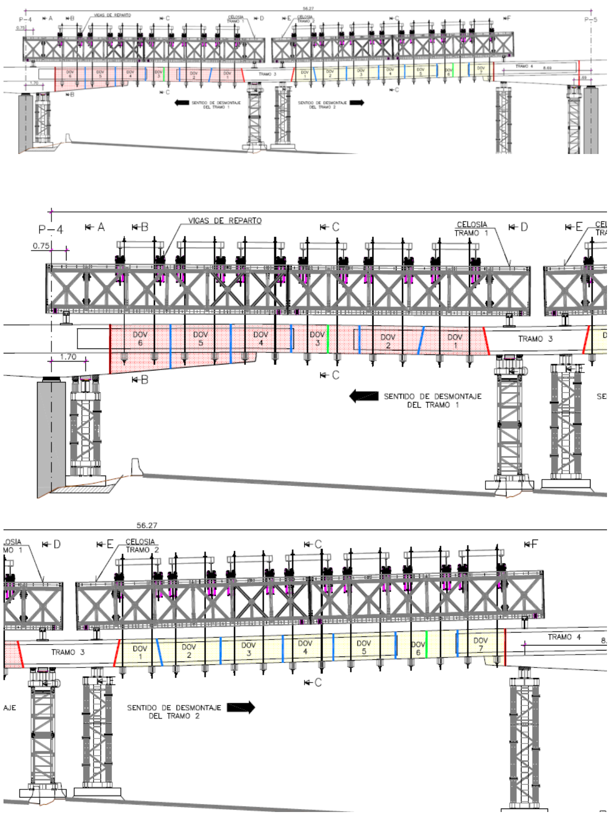


Figure 27. Deck sections distribution and cuts at span 5 over M-40.


Figure 28. Truss girders for auxiliary structure to dismantle main span over M-40.

The process of disassembly of this span may be summarized in the following phases:

- Installation of temporary towers.
- Loading of the towers by means of jacks supporting the deck.
- Drilling of deck holes for hanging bars.
- Installation of truss girders and rest of steel structure.
- Installation of bars and supporting beams under the deck and stressing of the bars.
- Cutting of segments in one half span.
- Removal of cut segments, lowering them on trucks by means of a crane.
- Cutting and removal of segments in the other half span.
- Disassembly of truss girder structure.

### *2.4. Auxiliary means*

To conduct the disassembly of segments in the typical spans, a 5886 kN crawler crane was used (Figure 29), whose position was carefully studied to minimize the translation operations according to the working distances. A working performance of one segment per day was achieved in general in the disassembly process, including cutting and removing of segments.


Figure 29. High-capacity crawler crane during disassembly operations.

As explained above, specific auxiliary construction equipment was designed and used to disassembly the main span over M-40 ring road between piers P4 and P5. This auxiliary structure consisted of four groups of truss girders placed on the deck.


Figure 30. Disassembly of the span over M-40 carriageways.


Figure 31. Detail view of truss girders for auxiliary structure.

Each of these groups, 24 m long and 1344 kN in weight, was composed by four truss girders 2.45 m high properly assembled covering each half span over M-40 (Figure 31). The truss girders were supported at their ends on transverse bottom beams at 22 m longitudinal distance, supported, in their turn, on the existing deck over piers P4 and P5 and over the central reserve where steel temporary towers were provided.

The structure of each group of girders was completed by pairs of transverse top IPE-550 beams 3 m spaced where additional secondary longitudinal beams were supported to anchor the vertical prestressing bars which the deck was hanged from.

## 3. THE NEW DECK

### 3.1. *General description*

The main constraint for the new viaduct deck was to keep the same alignment and span lengths as the old one, since the original piers and foundations are also kept with only some rehabilitation works. Therefore, to comply with all these conditions the viaduct has been designed, by Pondio Ingenieros, as a continuous deck with 17 spans, a total length of 560.4 m and variable span lengths, with a maximum value of 56.227 m, over the M-40 ring road [6][7]. The accurate span length distribution is: 20.484 + 32.627 + 35.196 + 38.243 + 56.227 + 32.727 + 36.674 + 38.669 + 29.466 + 28.869 + 36.507 + 29.437 + 29.431 + 32.914 + 32.924 + 30.045 + 19.972 m.

Figure 32. Precast beam before installation.

The deck section consists of a U precast post-tensioned beam curved in plan and a top concrete slab cast in place over thin precast slabs. The total deck is composed by 22 U beams fully connected along the deck by means of prestressing bars and tendons in such a way to achieve a continuous deck along all the length of the viaduct. The deck is 10.7 m wide to carry two 4.65 m wide lanes, hard shoulders included, and steel protection barriers placed on 0.7 m wide concrete kerbs.

All the precast concrete U beams were fabricated at Grupo Puentes factories of Prethor in Lugo (Spain) (Figure 32). The depth of the precast beams is, in general, constant of 1.70 m for most of the spans but it is in-creased linearly up to 2.55 m at the piers located close to the longest spans (piers P4, P5, P7, P10 and P11) (Figure 33). The length and weight of the beams is variable depending on their position along the deck and their depth. It is interesting to outline the following data:

- Longest U beam: Beam V-6 at midspan over M-40 (span length = 56.227 m) between piers P4 and P5. 36.187 m long and 1874 kN in weight with constant depth.
- Heaviest U beam: Beam V-3 at span between piers P2 and P3. 35.156 m long and 1923 kN in weight with constant depth.
- Shorter and lighter U beam: Beam V-11 at midspan over M-607 (span length = 36.507 m) be-tween piers P10 and P11. 16.467 m long and 961 kN in weight with constant depth.
- Variable depth U beams: at piers P4, P5, P7, P10 and P11. 12 m long and 1668 kN weight each one.

The properties of the materials used for this new deck are as follows:

- Precast beams concrete grade: C60/75-XC4.
- In place slab over piers P4, P5, P7, P10 and P11 concrete grade: C45/55-XC4/XF4.
- In place slab general: C35/45-XC4/XF4.
- Reinforcement steel: B-500B
- Prestressing steel: Y-1860C.

In general, the continuity of the beams over piers was achieved by means of prestressing bars joining the end diaphragm of both beams. For the connections between variable depth beams and constant depth ones also prestressing tendons were provided through the joints. All the joints between beams with 4 cm gaps were grouted before prestressing.

### 3.2. *Construction process*

Due to the specificity of this kind of modular bridge and the necessity of minimizing the traffic cutting on the roads crossing under the viaduct, the erection process for the beams has been very carefully studied and executed, with full control of all the movements which has allowed to place the beams at their positions with very reduced tolerances to provide continuity to the deck.

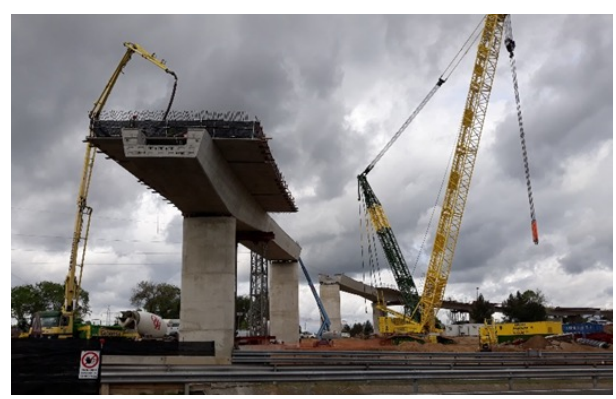


Figure 33. Construction of new deck over M-607 carriageways.

During this erection process auxiliary structures together with temporary bearings have been used to support some of the beams previously to the connections between them. Other beams have been temporary supported on the adjacent ones without temporary cantilever steel supporting structures. All the beams were placed in their definitive position by means of the same 5886 kN crawler crane used for the disassembly of deck segments (Figure 34).

Figure 34. Crawler crane during beams placement.

The erection process of this deck can be summarized in the following phases:

- ***Phase 1:*** (Figure 35)
- Placement of beams between abutment E1 and pier P2 and between piers P3 and P4, using one temporary tower at span P3-P4 to support the joint between variable depth and constant depth beams, connecting them by means of prestressing bars and tendons.
- Placement of beam between piers P2 and P3 and connections to the adjacent ones.
- Reinforcing and cast of the top slab 6.75 m wide central section over pier P4, 18.5 m long, by means of thin precast slabs supported on the beams (Figure 36).

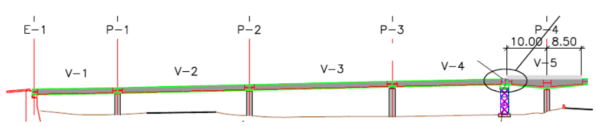



Figure 35. Construction of new deck: phase 1

Figure 36. Construction of top slab by means of thin precast slabs over precast U beam.

- ***Phase 2:*** (Figure 37)
- Placement of beams between piers P5 and P7 and between piers P9 and P10, using temporary towers at the three spans to support the joint be-tween variable depth and constant depth beams (Figure 11), connecting them by means of prestressing bars and tendons. Counterweights were used in some cases to balance the variable depth beams.
- Reinforcing and cast of the top slab 6.75 m wide central section over piers P5, P7, and P10, 18,5 m long, by means of thin precast slabs supported on the beams (Figure 38).

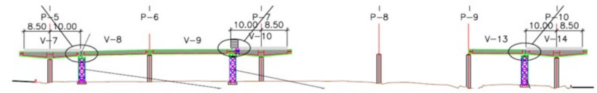



Figure 37. Construction of new deck: phase 2.

Figure 38. Top slab during reinforcing installation.

- ***Phase 3:*** (Figure 40)
- Placement of the beam between piers P4 and P5, over M-40 carriageways (Figure 39), supporting it on the cantilevers from the adjacent beams by means of temporary steel pieces, connection of them by means of prestressing bars and tendons.

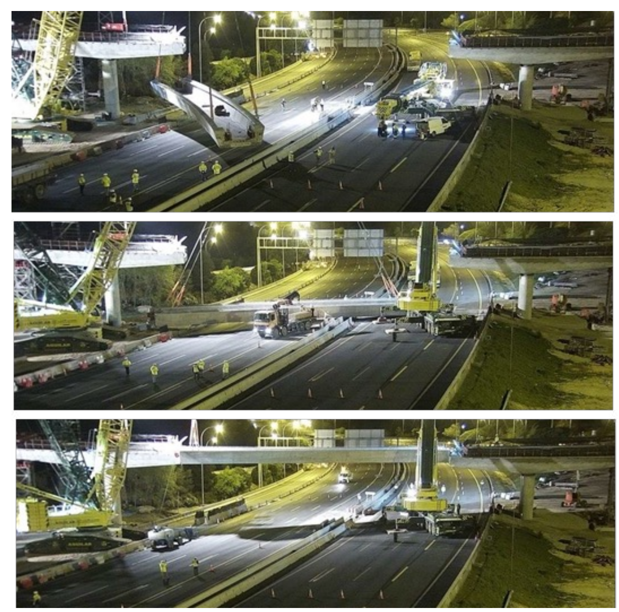


Figure 39. Erection of precast beam over M-40 main carriageways.

- Placement of beams between piers P7 and P9 and connections to the adjacent ones by prestressing bars.

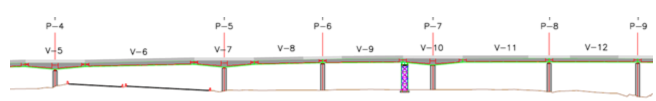


Figure 40. Construction of new deck: phase 3.

- Cast of the rest of the transverse section of the slab over piers P4, P5 and P7.
- Reinforcing and cast of the top slab 6.75 m wide central section over piers P1, P2, P3, P6, P8 and P9, ranging from 13 to 15 m long, by means of thin precast slabs sup-ported on the beams.

- Reinforcing and cast of the top slab 6.75 m wide central section at the rest of spans provided the slab over the two adjacent piers is already cast.

- ***Phase 4:*** (Figure 41)
- Placement of beams between piers P11 and P12, using one temporary tower to support the joint between variable depth and constant depth beams, connecting them by means of prestressing bars and tendons.
- Reinforcing and cast of the top slab 6.75 m wide central section over pier P11, 18.5 m long, by means of thin pre-cast slabs sup-ported on the beams.
- Placement of the beam between piers P12 and P13 and connection to the pre-ceding beam.

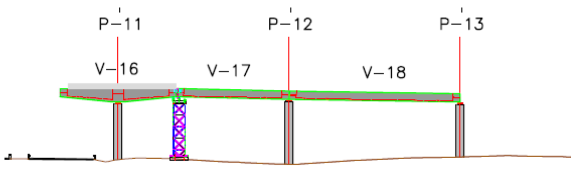



Figure 41. Construction of new deck: phase 4.

- ***Phase 5:*** (Figure 43)
- Placement of the beam between piers P10 and P11, over M-607 carriageways (Figure 42), supporting it on the cantilevers from the adjacent beams by means of temporary steel pieces, connection of them by means of pre-stressing bars and tendons.

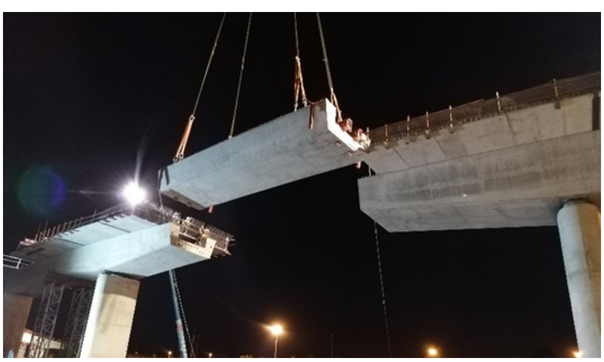


Figure 42. Erection of precast beam over M-607 main carriageways.

- Placement of the beam between piers P13 and P14 and connections to the adjacent ones by prestressing bars.

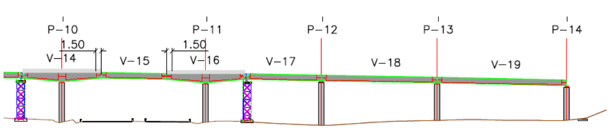



Figure 43. Construction of new deck: phase 5.

- Cast of the rest of the transverse section of the slab over piers P10 and P11.
- Reinforcing and cast of the top slab 6.75 m wide central section between piers P8 and P10.

- ***Phase 6:*** Placement of beams between piers P14 and P16 and connection between them and to the preceding beams (Figure 44).

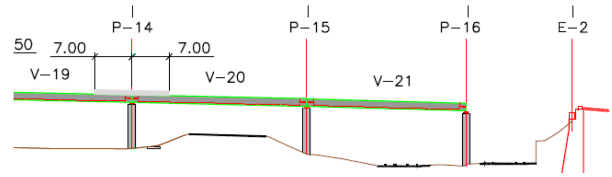



Figure 44. Construction of new deck: phase 6.

- ***Phase 7:*** (Figure 45)
- Placement of the beam between pier P16 and abutment E2, connecting it to the preceding beam by means of pre-stressing bars. It must be remarked that the beams over the railway lines were placed in position during two con-secutive nights, only three hours per night, without rail-way traffic disruption).

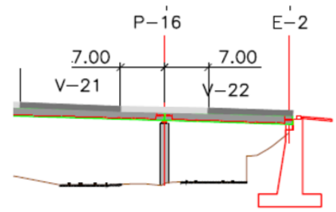



Figure 45. Construction of new deck: phase 7.

- Reinforcing and cast of the top slab 6.75 m wide central section over piers P12, P13, P14, P15 and P16, ranging from 13 to 14 m long, by means of thin precast slabs sup-ported on the beams.
- Reinforcing and cast of the top slab 6.75 m wide central section at the rest of spans provided the slab over the two adjacent piers is already cast.
- Cast of the rest of the top slab transverse section.

Figure 46. Bottom view of the new deck during construction.

The object of this complex construction process is to guarantee that during its execution the forces induced at the beams sections and slabs are always under the values of resistance of those elements, which is governed by the service loads and conditions, together with the stability of all the precast elements during the construction process (Figure 46).

### 3.3. *Existing facilities*

Concerning the existing facilities in the zone, special attention was paid to the underground water sewage facilities. In the site area three main water pipes were detected with diameters ranging from 1 to 2 m at variable ground depths of 0,65 to 2 m from surface level. No cranes installation was allowed over the pipe alignments and only truck traffic was permitted to run on this area. Specific analyses were carried out to check the pressures transmitted to the soil, not greater than 55 kN/m², and to guarantee the safety of the existing facilities.

## 4. OTHER REPARATION ACTIONS

The analysis of the existing substructure, piers and foundations, lead to the conclusion that no deterioration process had taken place in those elements and that they had enough capacity to withstand the loads transferred by the new deck. Because of that and to ensure an increased durability, only reparation of the external surface was found necessary. Nevertheless, to increase the service life of the piers a reinforced concrete cover 15 cm thick was provided along the whole height of the external surface of all the piers (Figure 47). Additionally new bearings and joints were installed since the old ones have arrived the end of their service life. The reparation of the piers and the concrete cover were conducted before installation of beams for the new deck. The definitive bearings were in-stalled during deck construction according to the construction process.

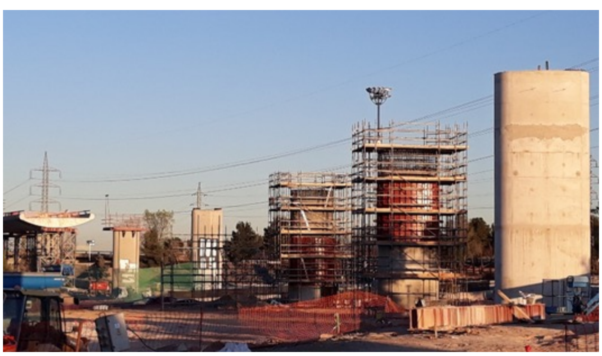


Figure 47. Rehabilitation of piers before deck construction.

## 5. CONCLUSIONS

Several conclusions may be got from this construction experience, from both, the point of view of conservation and that of construction itself. The process of concrete degradation in bridges takes place in some cases quicker than expected due to the effect of environmental conditions combined with specific material properties. The advance in material behaviour knowledge, the difficulties to recover the lost mate-rial properties and the cost of the options for rehabilitations may drive to the decision of replacement of structure instead of its rehabilitation, which is what happened with the deck of the viaduct object of this paper. In this paper it has been shown that it is possible to carry out such operations keeping in service for the traffic the rest of the link, only with partial traffic diversions and cuttings.

The result is a bridge with a new deck fully consistent with the current standards increasing the service life of the bridge more than a hundred of years (Figure 48). Of course, one of the problems is to keep, as much as possible, the service conditions of the road link, in this case, allowing traffic flow during all the construction process, which has as consequence the optimization of methods to increase productivity and to reduce the total construction period.

Figure 48. View of the bridge after completion.

The expertise in bridge construction and a close coordination between construction itself and concrete precast fabrication are one of the keys to guarantee the quality, efficiency, and success of all the processes up to the completion of the bridge.

Special mention shall be made to the importance of a proper geometric and setting-out control during beams fabrication and during beams assemblage. Since only 4 cm wide gaps were provided between precast beam, any mistake could have had fatal consequences. For this reason, it is necessary a technical office support team to check all the construction da-ta and a full coordination of this team with the in-place construction team. The accurate fabrication process and the installation control by means of cranes should be developed under closed supervision.

The bridge with the new deck was opened to traffic in August 2020 after a record time of nine months of works, including disassembly of the old deck, reparation and reinforcement of the substructure and fabrication and erection of the new deck. The main conclusion to be extracted from this experience is that when bridge structural properties are proved to be poor enough to provide appropriate service conditions, the option of construction of a new deck should be considered feasible even in traffic congested areas as the reference link.

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