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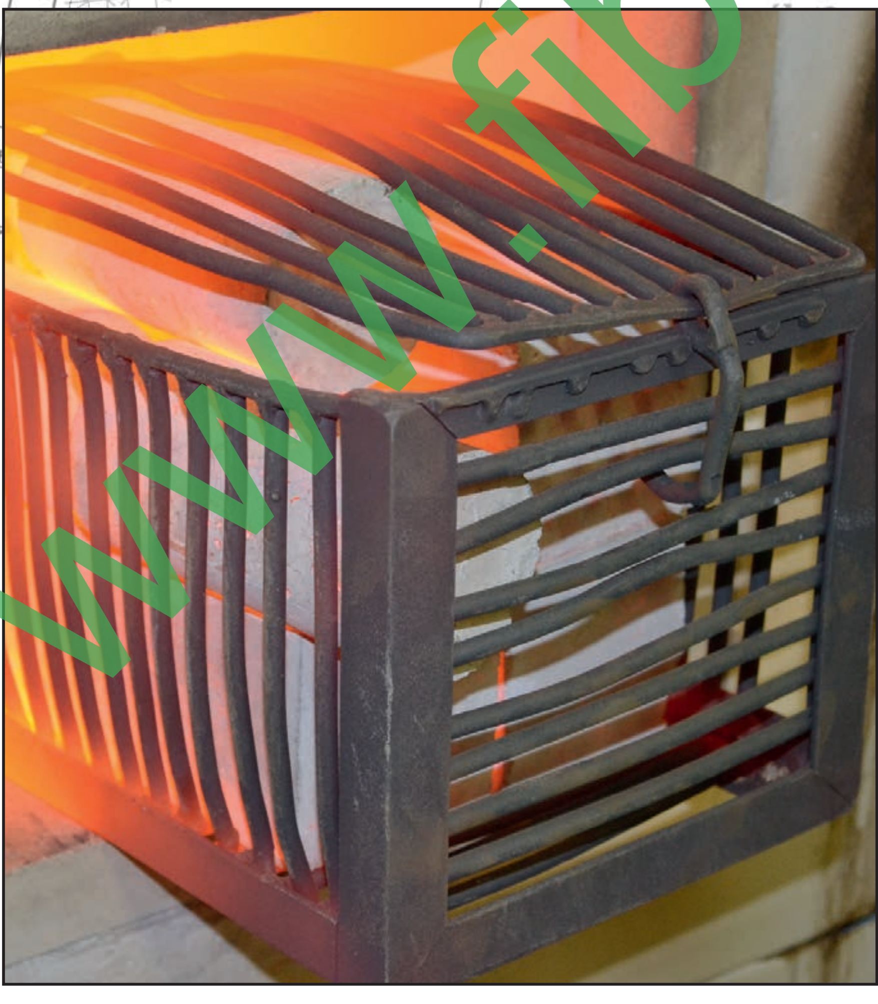
CONCRETE STRUCTURES

ANNUAL TECHNICAL JOURNAL



2012

Vol. 13


SPECIÁLTERV
design
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www.specialterv.hu

CONCRETE STRUCTURES
Journal of the Hungarian Group of ***fib***

Founded by: Hungarian Group of ***fib***
Publisher: Hungarian Group of ***fib***
(***fib*** = International Federation for Structural Concrete)

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WEB http://www.fib.bme.hu
Editing of online version:
László Bene

Layout and print:
Csaba Halmai
Navigar Ltd.

Price: 10 EUR
Printed in 1000 copies

HU ISSN 2062-7904
online ISSN: 1586-0361

Cover photo:
Concrete specimens heated up to 1000 °C
Photo by: Olivér Czoboly

CONTENT

Sponsors:
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REINFORCED CONCRETE FRAME OF THE PAINT SHOP

MERCEDES-BENZ FACTORY COMPLEX IN THE CITY OF KECSKEMÉT, HUNGARY




József Almási – László Polgár – Pál Sterner – Péter Varvasovszky

The article is presenting the modified structural frame design of a paint shop which was comprised of heavy precast concrete elements with moment bearing joints at the time tendering. The modified structural design provided a lighter structural framing system accommodating the application of the locally more employed construction and production technologies, meeting all the requirements of the tendered technical requirements by using lighter precast elements, composite structural framing system, more reliable construction methods for moment bearing connections accommodating much greater manufacturing and erection tolerances for the precast elements, therefore, reducing the construction cost and time.

Keywords: reinforced concrete frame, precast concrete elements, moment bearing connections, modified construction technology, optimized construction cost

1. INTRODUCTION

Mercedes-Benz invested 800 million Euros to build a new car manufacturing plant located in the city of Kecskemét, Hungary. The total built in areas of buildings are 300.000 m^2.

One of the technologically most complex buildings of the new car manufacturing plant is the paint shop.

In the conceptual phase of the project the architectural design was prepared by the German Kohlbecker Ltd. and the Hungarian CÉH Co. The conceptual structural design was the work of the German BKSi. In the later stage of the design the structural drawings for permit and construction were prepared by the Hungarian Sterner Ltd.

The bid of KÉSZ Co. won the tender. The entire construction of the project was awarded to KÉSZ Co. – as general contractor - and CAEC Ltd. – as consulting engineers – was hired by the general contractor to provide alternative structural solution for the framing of the tendered paint shop with restriction as follows:

- the alternative structural solution has to preserve the architectural and technological content of the tender document.
- the owner explicitly asked for normal reinforced concrete structure excluding any pre/post tensioning option.
- the geometry of the building must remain and the alternative structural system has to bring cost, time and constructability benefits to the owner and the general contractor.

CAEC Ltd. proposed a composite reinforced concrete structure comprised of precast concrete elements without pre- or post-tensioning and cast in situ concrete options by including the future structural sub-contractors, namely PAMINVEST Co., BAMTEC Ltd. and DVB Ltd. The newly assembled team of structural consultants, subcontractors worked very closely with the consulting team to develop optimal and practical structure for the paint shop to achieve the desired outcome of cost and time saving. It is important to note here that the authors would like to express their appreciation to all participants who were part of the team and contributed to the successful completion of the paint shop. The meticulous listing of the participants of the design team and their contribution is important due to another reason, namely it accentuate the broad range of international cooperation, the application of the common Eurocode standards which was unquestionably the most important aspect of the success of the design work.

2. GENERAL DESCRIPTION OF THE STRUCTURAL SYSTEM OF PAINT SHOP

The planar dimensions of the paint shop are 63.0×333.0 m and the orthogonal grid spacing determining one panel dimension bordered by four columns is 12 × 10 m generally.

Due to the length of the building the structural consultant created four independent structural units having length of 70 to 100 m (*Fig.1*). These planar units were separated by expansion joints running along the full short length of the building.

There are three functionally distinctive floors in the paint shop. The first level located around 7.5 m above the ground floor was constructed as precast and cast-in-situ composite floor slab covering the entire foot print of the building.

The second and third floors have structural steel primary framing (beams and columns) and cast-in-situ concrete slab is the secondary framing element supported by the primary framing. It has to be noted that the third floor does not cover the entire foot print of the paint shop. The finished structural floor elevations of the second and third floor plates are 20 m and 28 m above ground floor elevation.

The scope of the article covers only the structural aspects of the first floor slab (+7.50 m) of the building as shown in *Fig. 2*

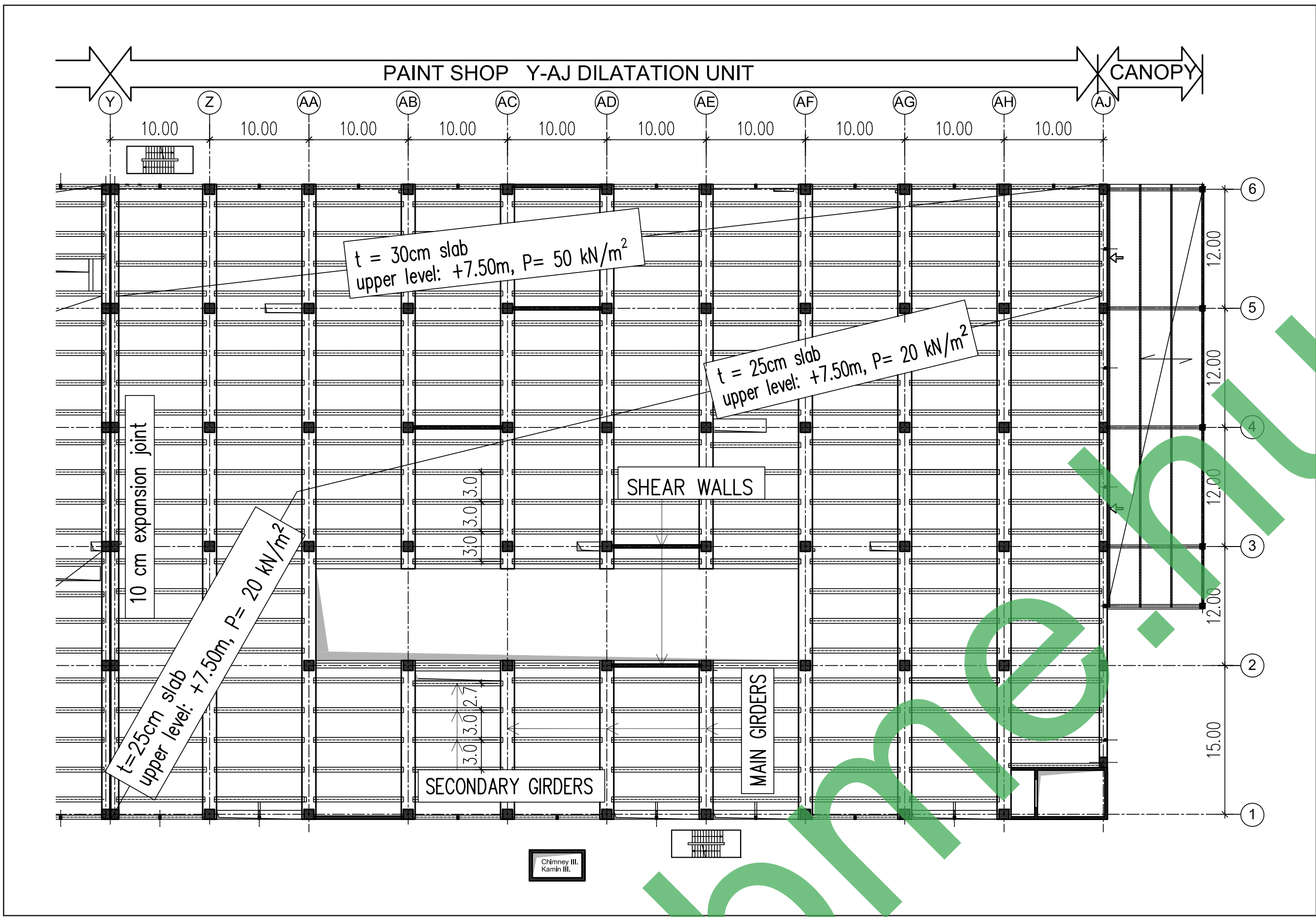

Fig. 1: *Layout of a structural unit on +7.50 m level*

marked with dotted line wire frame. The structural description of the two level steel frame is beyond the scope this paper. We are only referring to the structural steel frame because it is supported by the reinforced concrete frame of the first floor.

The magnitude of service (un-factored) level live load of the first floor is p = 20 kN/m^2 generally. There is a 15 m wide band of the first floor where the magnitude of live load is p = 50 kN/m^2. This high intensity load was due to the location of the painting robots. Their operational requirement allows very small magnitude of slab deflection.

3. DESCRIPTION OF THE ORIGINAL STRUCTURAL CONCEPT DESIGN

The original structural concept envisioned the application of a moment bearing sway type framing system for the paint shop which was assembled of heavy precast structural components.

The architectural and technological requirements allowed placing shear walls running only parallel to the longitudinal axis of the building. Therefore, sway type moment bearing multi-level (2D) frames secured the cross directional stiffening of the building and the frame action was perpendicular to the shear walls. This combined system provides adequate resistance against lateral forces induced by wind, seismic force corresponding to maximum horizontal acceleration (a_{gr} = 1 m/s^2). There was no special consideration given to the vertical acceleration component of the seismic – Raleigh type – waves. The foundation consultant selected pile foundation for the building due to the uncertain load bearing characteristic of the soil (Loess type) and the magnitude of the column forces.

The long foundation piles (6, 8 or 9 piles in one group) were connected at top with large cast-in-situ reinforced concrete pile cape. A typical cross section of the building is shown in *Fig. 2*.

The characteristic dimensions of the precast components from the tender document are as follows:

Columns: 1.00 × 1.00 m or 0.80 × 1.00 m cross section, G = 25 t

Main girders:1.40 × (1.55+0.25) m, G = 60 t.

Secondary girders: 0.50 × (0.75+0.25) m or 0.50× (1.00+0.25) m, G = 11.2 or 14.0 t.

The floor slab comprised of 8 cm thick precast cradle panels forming elements and 17 cm thick cast-in-situ reinforced concrete topping.

Fig. 3 shows the typical cross section of the building slab located at elevation +7.50 m and *Fig. 4* shows the connection details.

The moment bearing frame connections were designed by using GEWI bolted connections and the gaps between the intersecting members were injected with speciality grout according to the tender document shown in *Fig. 4*.

4. INTRODUCTION OF AN ALTERNATIVE STRUCTURAL SOLUTION

CAEC Ltd. as structural consultant with a group of Hungarian subcontractors collaboratively worked out a new structural design which provided structural solution for reducing the construction time, cost, adapted better to the Hungarian construction practice and resources than the sturctural scheme provided in tender documentatiton. Priority requirement was to reduce the weight of precast concrete main girders because

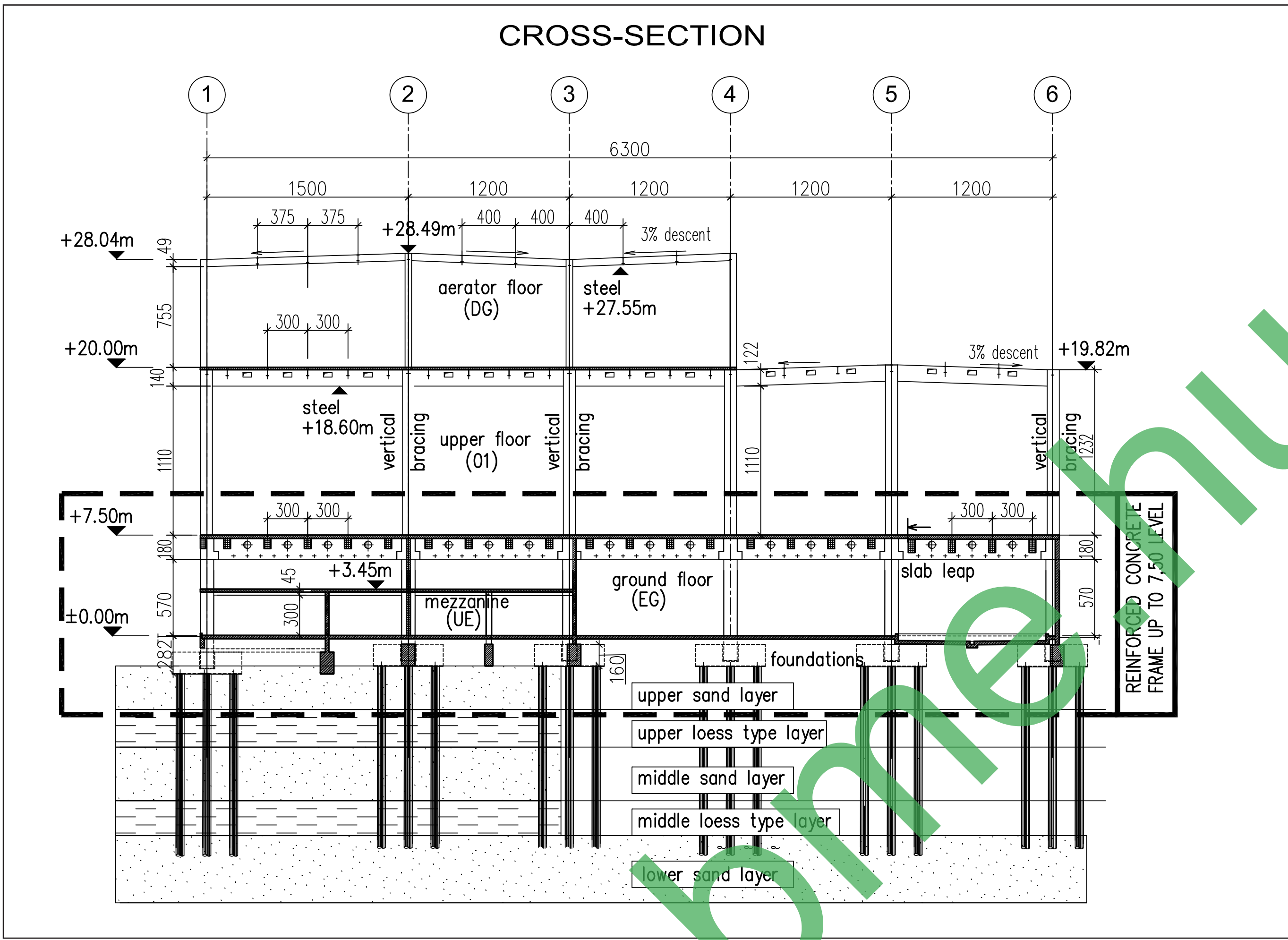

Fig. 2: Cross section of the building - schema of the structural frame (detail from tender document)

the weight of originally designed girder was so excessive that it created an insurmountable logistical problem with the transportation and lifting.

The new corrected structural design kept the concept of the tender meaning the rigid two way system concept and it changed rather the building method of structural frame of the paint shop. The dimensions of the primary frames remained unchanged because technological design issued with the tender document.

According to the new structural version the design team used Partially Precast System.

This means a composite system, which comprises precast elements and cast-in-situ additional structural enhancement which will be explained in detail later in the paper.

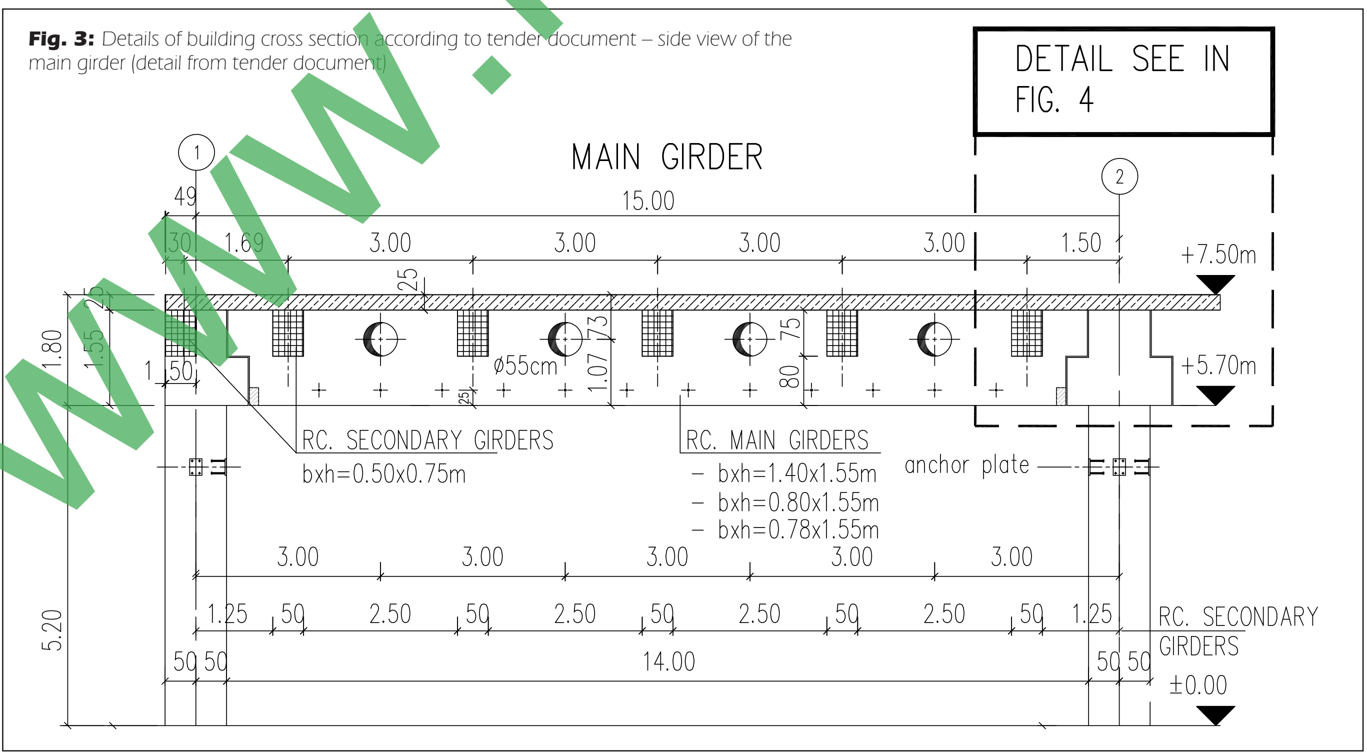

Fig. 3: Details of building cross section according to tender document – side view of the main girder (detail from tender document)

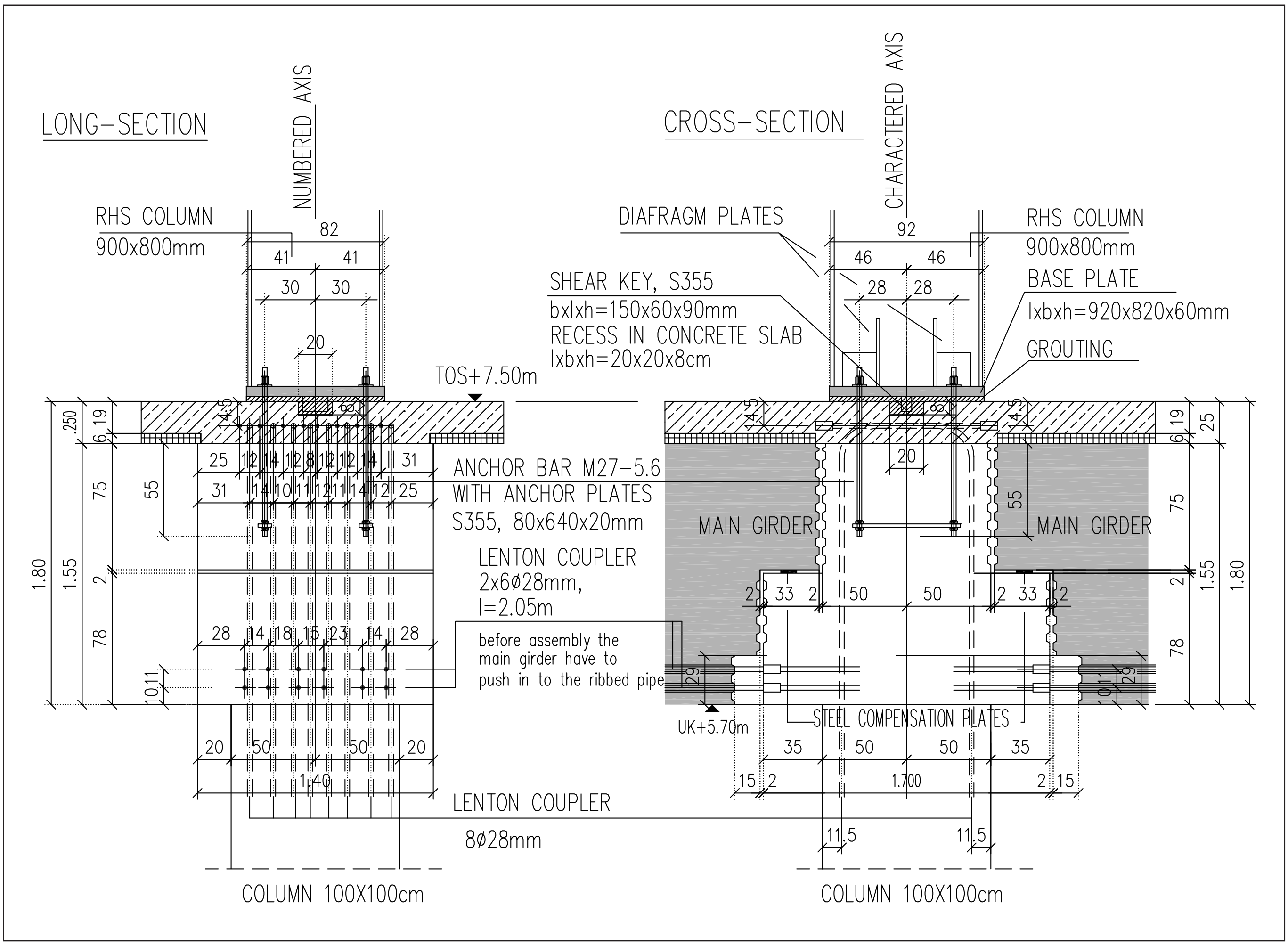

Fig. 4: *Column-main girder rigid connection detail (detail from tender document)*

With this method the weight of the precast concrete main girder was substantially reduced and the use of the precast formwork enabled the contractor to speed up the schedule timing greatly. The columns were poured on site and the upper 80 cm high part of the main girders was also a cast-in-situ reinforced concrete. This condition is shown in *Figs. 5 and 6*. The new structural detail allowed the construction of more reliable and constructible rigid moment bearing beam/column connections than the tender document provided structural design.

Fig. 6 shows the cross and longitudinal sections of the alternative beam/column connections.

Geometrical modification was only possible for the foundation. The new structural design favoured the application of the cast-in-situ columns as opposed to the precast columns by the tender document. With the construction of the cast-in-situ columns the contractor had the opportunity to avoid the construction of the cup shaped sockets for the connections of foundation and precast columns. The cast-in-situ option provided great opportunity to reduce the dimensions of pile caps and to make the connections simpler and more reliable without changing anything in the spacing and numbers of piles which was one of the owner's requirements. The new structural design kept the original dimensions of the main girders (1.40 × 1.50 m), however only the lower half part of the girder is fully completed and the remaining part has only outer shell to facilitate the on-site concrete pouring. With this arrangement the weight of the main girder became manageable for transportation and erection. Fig. 8 shows the end segment of

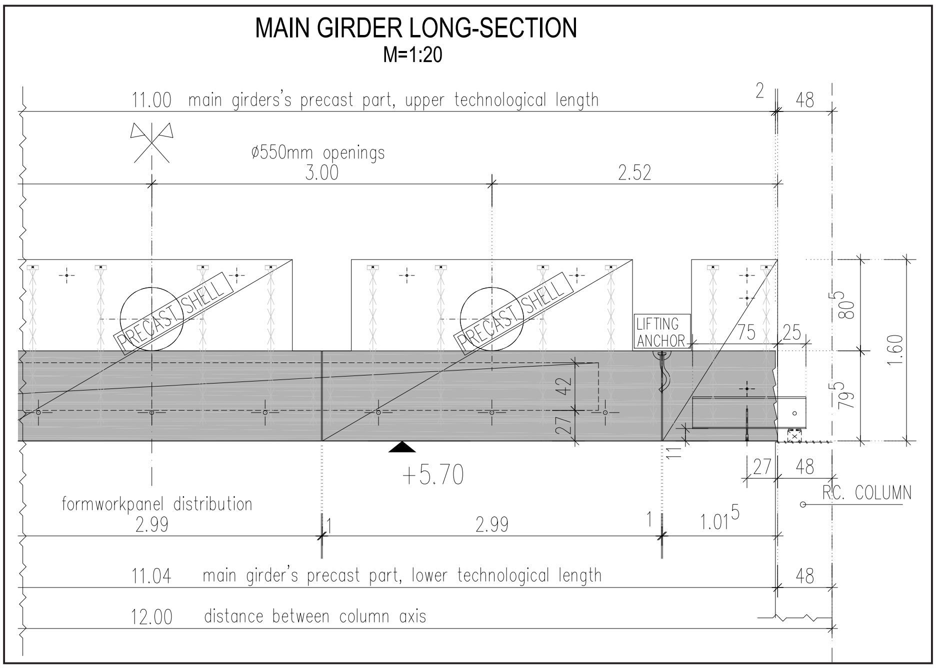

Fig. 5: *Part elevation of the main girder at column support*

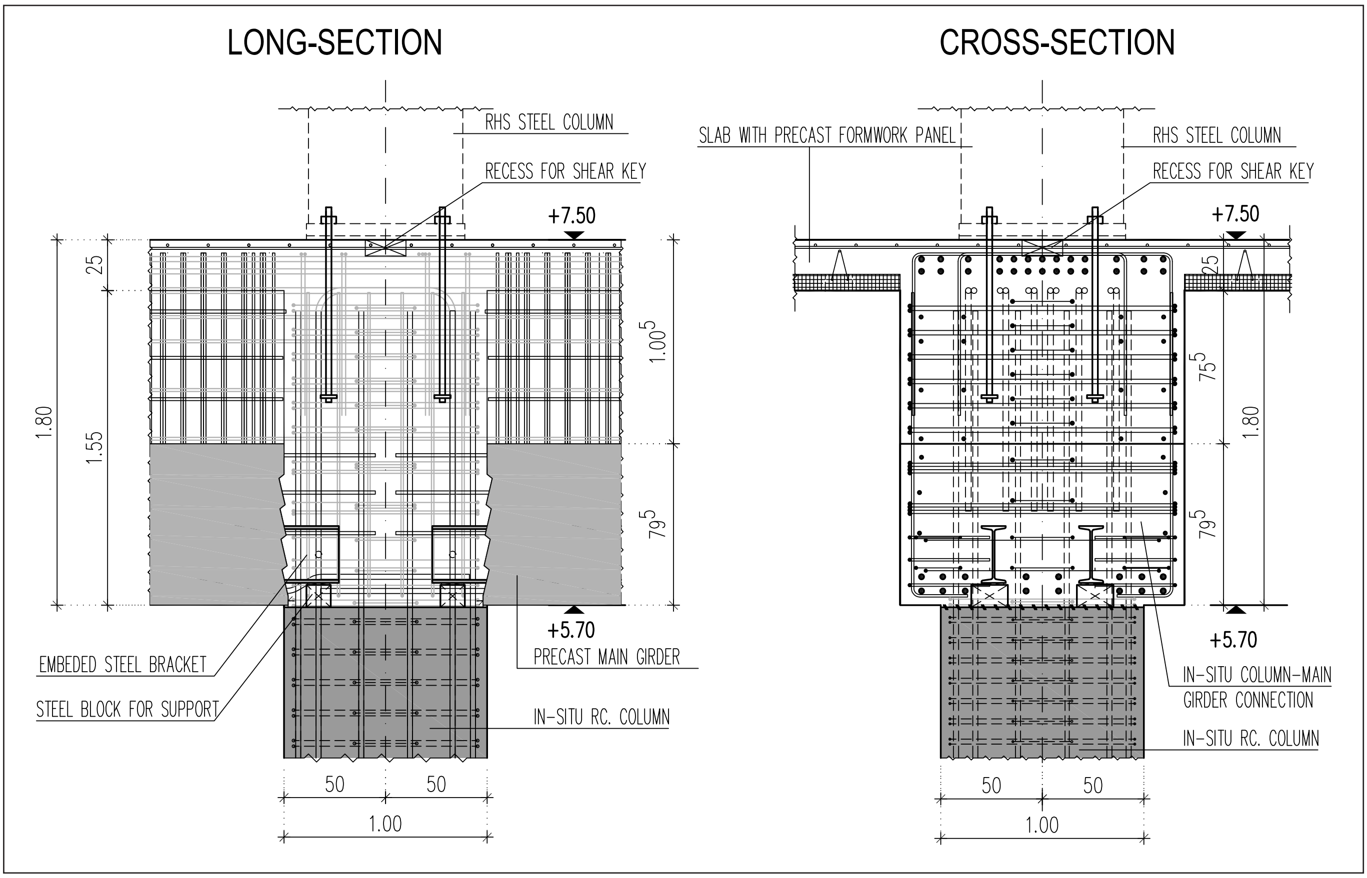

Fig. 6: Connection details of column and main girders

the main girder as it was stored on the yard of the manufacturing facility. The exact cross sectional dimensions of the main girder are shown in *Fig. 7*.

The precast concrete shell of the main girder enabled the contractor to get easy access to the column / girders intersections and it also allowed the simple connection between the secondary girders framing into the main girder and it allowed the on-site concrete pour without any further formwork construction. In order to make the precast bottom segment of the main girder lighter the consultant designed longitudinal

Fig. 7: Cross sections of the main girder

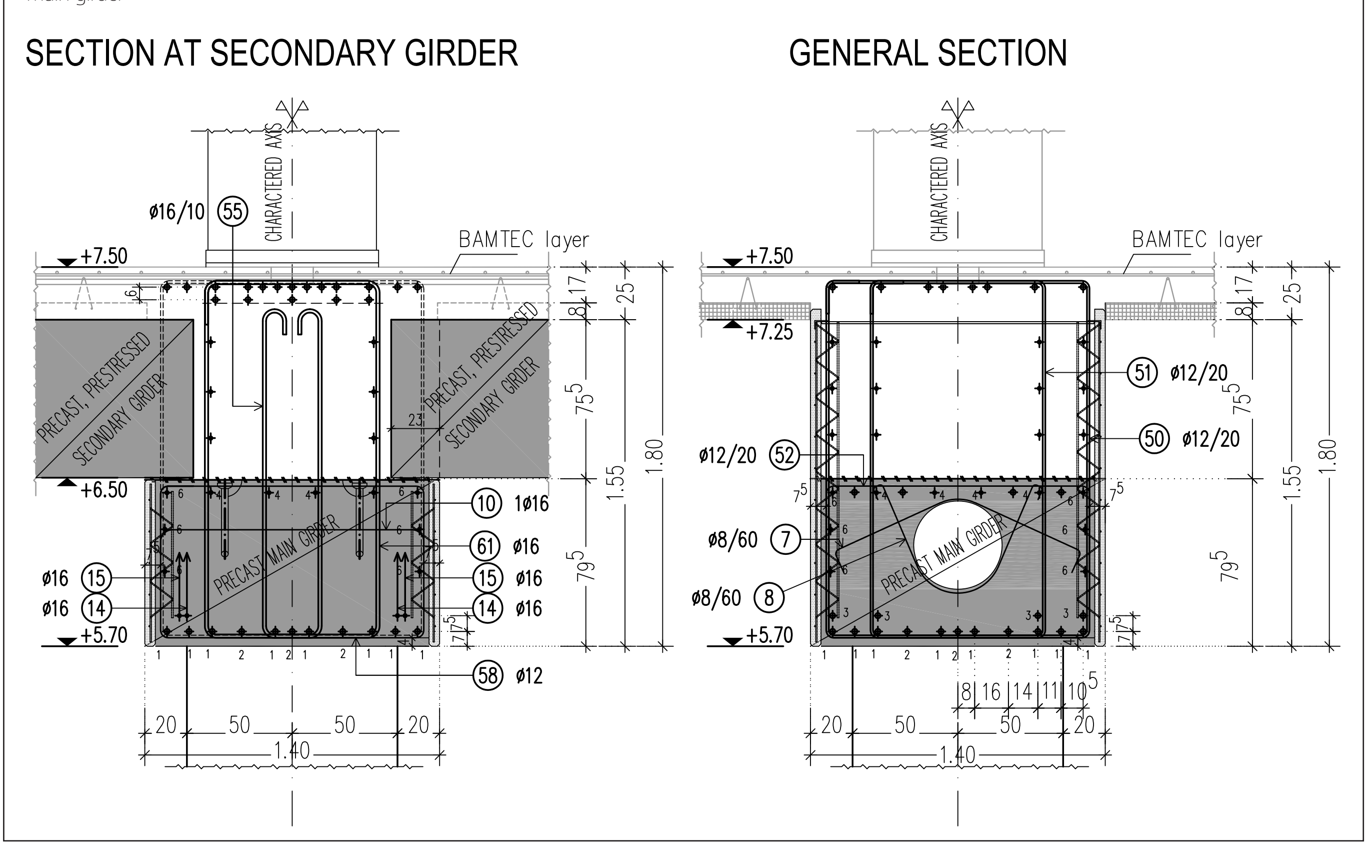

Fig. 8: Precast concrete main girder in the manufacturing yard

Fig. 9: 100 cm deep secondary girders with upper reinforcement before assembling on site

Fig. 10: Precast structure of the slab before concreting with temporary shoring structures

Fig. 11: Placing BAMTEC reinforcement on precast formwork elements

placed pipe duct. Other circular ducts were perpondicular to the axis of the main girder allowing the free crossing of various electrical and mechanical installations.

The extension of the vertical legs of shear and torsion stirrups extended above the precast bottom part of girder and enabled the composite action between the precast and the cast-in-situ segments along the horizontal cold joints running along the entire length of the main girder.

The presented solution was the first case used in Hungary according to the present knowledge of the authors.

The formwork and the construction expediency did not allow designing traditional short cantilevers providing support for the main girders. Therefore, the design team used embedded I shaped steel sections which were projecting beyond the ends of the main girder into the supporting main cast-in-situ concrete columns. In order to assure the formation of the adequate bearing surface the projecting steel beams were placed on solid bearing blocks. The spacing of the column vertical reinforcement made it feasible to avoid the interference with the bearing blocks and the steel I shaped short beams. The precast ends of the main girder have series of grooves and projections designed to act as shear keys. Therefore, the shear force transfer has two path ways. One of them is the shear capacity of the embedded I shaped steel beams and the second the shear key formation at the ends of the precast girders. There was a coordinated effort of all team members that connection between the precast main girders and the cast-in-situ concrete columns to meet the stringent requirement of the on-site construction tolerance.

Secondary girders were either 75 cm or 100 cm deep, depending on the live load. They were supported by the precast part of the main girder (*Fig. 7*). The ends of secondary girders were indented (*Fig. 9*) in order to achieve better connection between precast and in-situ concrete. The upper reinforcement bars of secondary girder were already placed inside the stirrups before assembling (*Fig. 9*). As the secondary girders were already placed, upper reinforcement had to be pulled properly above the main girders.

Due to the magnitudes of seismic action induced horizontal loads acting on the rigidly connected column/girder connections the Code EN-1998 requires a substantial amount of shear reinforcement in order to attain the adequate level of two way shear and moment bearing capacities of the connections. This reinforcement is shown in *Fig. 6*.

The density of the shear reinforcement caused difficulties during the rebar placement but with correct detailing and keeping the set placing sequences the contractor managed to install the correct rebar cage without any problem in exemplary manner.

The main girders had to be supported by temporary shoring system having load bearing capacity of 900 to 1000 kN because the half dimension precast girder did not have the load bearing capacity to carry the self-weight of the cast-in-situ concrete including the weights of precast secondary girders, precast formwork elements, and the cast-in-situ concrete slab topping.

Fig. 10 shows the temporary shoring of the main girders during construction phase. The temporary shoring structures were placed on temporary foundation made of precast concrete elements.

The floor slab formwork was made of stay in place precast thin slabs and the cast-in-situ concrete topping having thickness of 17 cm was reinforced with rolled out carpet reinforcement patented by BAMTEC Ltd. (*Fig. 11*). This patented reinforcing arrangement can assure that the optimal

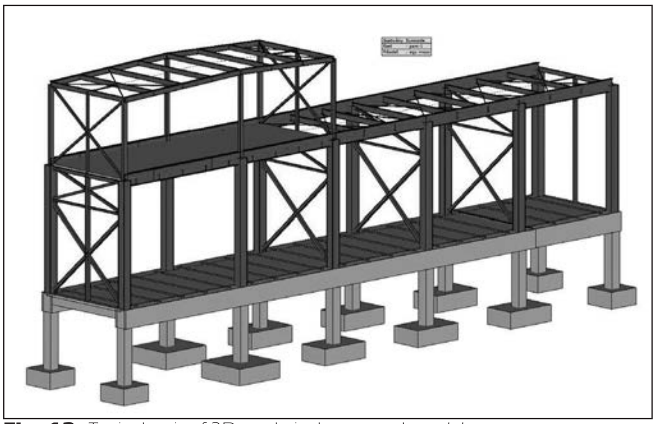

Fig. 12: Typical unit of 3D analytical structural model

amount of reinforcement is placed in the slab and BAMTEC method is vastly reducing the installation time of the slab reinforcement providing substantial saving on the material and labour cost sides.

5. DESCRIPTION OF THE ANALYTICAL STRUCTURAL MODEL

The structural consultants used 3D finite element model which was created by the structural engineers of Sterner Ltd. during the permit phase. They used the AXIS VM 9.0 finite element software for setting up the analytical model of the building. Each building part separated by expansion joints was handled as separate and independent structure during the analytical phase of design process. The structural engineers created precise models taking into account the soil and superstructure interaction during seismic action and modelled the piles as spring supports for the pile caps. The upper two level steel frame was modelled as linear element with the proper restraining conditions like pinned, partially restrained or fully restrained 3D structure. The reinforced concrete part of the building was modelled as shell and slab elements. Under such modelling technique the dynamic properties of the building like eigen-frequencies, eigen-vectors, acceleration and velocity vectors were adequately captured. The structural model did not venture into the time history analysis or even more sophisticated realm of the analysis like plastic behaviour of the system components or site specific seismic data application.

The magnitudes of the spring supports for the pile caps were given by the geotechnical consultant (Smolczyk & Partner GmbH) specifically related to the physical properties of the loess type soil matrix. The models considered that the connections between the pile caps and cast-in-situ concrete columns are fully restrained and rigid.

The analytical model of the 1st floor slab (+ 7.50 m) comprised identical size rectangular shell elements supported and stiffened by the main and secondary girders with full cross sectional contribution to the structural stiffness.

Fig.12 shows a segment of the analytical model located between two grid lines as typical unit of the analytical model.

Modelling of the superstructure steel and of the reinforced concrete frames was not extremely challenging task. However, the correct analytical capturing of the foundation comprising piles and connecting head caps left many disputable issues

Fig. 13: Finished structure inside

because of many uncertainties arising from the soil/structure interaction. It needed considerable degree of engineering judgment from all sides of the consulting engineers to arrive to a mutually acceptable conclusion. Eventually it became necessary that CAEC engineers corrected a few aspects of the design during the construction phase.

The horizontal and vertical spring bedding constants of the individual piles are different under static and dynamic loading conditions. Addition to this the load bearing characteristics of individual pile is grossly influenced by the group action of piles related to the pile spacing, number of piles connected to one pile cap.The pile arrangement and other site conditions are influencing the eigen-frequencies of the building frame and in return the response of the structure (like acceleration, velocity, displacement) for the seismic action.

Therefore, the rigidities of the supports were determined in many steps taking into account the vertical and horizontal displacements of the piles under short and long duration loads, the actual pile capacities under displaced geometry and the response of the superstructure.

The internal forces of the structural components were determined by the 3D analytical model but for the actual member proportioning in house developed softwares were used frequently with the utilization of the Friedrich Lochner software package.

6. SUMMARY AND CONCLUSIONS

In the tender document of the paint shop building of Mercedes-Benz new manufacturing plant the structural engineers envisioned a structural framing system assembled of heavy precast concrete components (columns and girders) rigidly connected together with the application of complicated details and construction methods.

Due to the very short construction time allocated to the project and the capability of the general- and subcontractors we decided to seek out a more practical, reliably constructible structural system meeting all the basic requirement of the tender document and provides benefit for the owner and the general contractor. The new structural frame fully considered the originally designed framing system up to the 1st floor (+7.5 m) uses all advantages of the partially precast concrete and cast-in-situ system and integrates the steel building frame located above the 1st floor without any deviation from the requirement of the tender document considering the full exclusion the possibilities of any additional forces or deflections might be caused in the steel superstructure (*Fig.13*).

Among the chief considerations there were the following items like adverse climatic/weather conditions during the construction, capacity of the available and existing lifting equipment's for the precast concrete manufactures, the availability of large capacity mobile cranes for site erection, improvement of quality of the site work, improvement of the quality of the coordination, scheduling and monitoring of the construction and the assurance of the overall quality of the structure.

In order to reach the above listed goals there was an exemplary cooperation among the stake holders including the manufacturers, erectors, design teams, construction and project managers.

7. ACKNOWLEDGEMENTS

The authors are expressing their sincere appreciation and thankfulness to all participants who contributed to the successful completion of the paint shop building including the original engineering group BKSI GmbH and the construction management group of the owner.

This building project proves again that the design and construction technology aspect shall work in a synchronized way to attain the optimum solution in complex building structure like the present paint shop.

This building is a proof for the international cooperation among all stake holders by using the unified codes, advanced applications of various computer softwares, and project management techniques.

The authors are very grateful for all those organizations and individuals who assisted in the project with their ideas, practical solutions, advices and their diligent works bringing this project to a successful completion.

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