DESIGN OF AN UNCONVENTIONAL BRIDGE USING CONVENTIONAL METHODS: STATE OF THE ART CAST IN PLACE DEPARTURES TERMINAL BRIDGE OF CAIRO INTERNATIONAL AIRPORT

K. K. Oncu[1] and H. K. Dal[2]

ABSTRACT

The Bridge Engineering technology has been evolved in past decades has developed significantly so that the unconstructible has been constructible, the impossible spans became possible. These epic engineering stories are in fact the locomotive of bridge engineering industry. However there are many talented engineers that do not always get a chance to participate in these type of projects. These engineers ate tasked with improving efficiency and effectiveness of design and construction of more common type of bridges.

The bridge structure at new Cairo International Airport Project is an example to above mentioned type of structures. A structure of 300m long fish shaped structure where at widest section is 70m. Besides the complicated plan geometry, beneath the bridge the area is highly utilized with Baggage Handling System, office areas, parking lot, in addition to an existing skyway structure which needs to be structurally revised due to elevation limitations. All these different architectural requirements demand various solutions that need to be orchestrated into the structural design of this airport bridge.

This complexity is not conventional for even an airport bridge structure. In addition to the geometrical and architectural challenges, structurally this bridge needs to be designed as cast in place reinforced concrete with 21m long spans. All the above factors make the design very exciting for bridge engineers.

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Design Of An Unconventional Bridge Using Conventional Methods: State Of The Art Cast In Place Departures Terminal Bridge Of Cairo International Airport

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Introduction

Cairo International Airport (IATA: CAI, ICAO: HECA) (Arabic: مطار القاهرة الدولي Maṭār al-Qāhirah al-Duwaliyy) is the busiest airport in Egypt and the primary hub for EgyptAir, a member of the Star Alliance. The airport is located to the northeast of the city around 15 kilometers (9.3 mi) from the business area of the city and has an area of approximately 37 square kilometers (9,100 acres). [1]

The airport is administered by the Egyptian Holding Company for Airports and Air Navigation, which controls the Cairo Airport Company, the Egyptian Airports Company, National Air Navigation Services and Aviation Information Technology, and the Cairo Airport Authority. In 2004, Fraport AG won the management contract to run the airport for eight years, with options to extend the contract twice in one year increments.[2]

Cairo International is the second busiest airport in Africa after OR Tambo International Airport in Johannesburg, South Africa. Over 45 passenger airlines use Cairo airport (including charter airlines) and 9 cargo airlines. Egypt Air is the largest operator at the airport.

The airport has four terminals, with the third (and largest) opening on 27 April 2009 and the

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Seasonal Flights Terminal opening on 20 September 2011. Terminal 2 was closed in April 2010 for major renovation works to the building's structure and facilities. A third parallel runway replaced the crossing runway in 2010.[3] Runway 05L/23R is 3,300 meters (10,800 ft) long, 05C/23C has a length of 4,000 meters (13,000 ft), and the new runway is designated as 05R/23L and is approximately 4,000 meters (13,000 ft).

Terminal 2 was inaugurated in 1986 with 7 boarding gates. [4]It primarily served European, Gulf and Far Eastern airlines. The terminal was closed in April 2010 for complete renovations which will start in 2012 and last 36 months. The architecture of the terminal building limited the opportunities for further expansion which necessitated the entire building to be closed for major structural overhaul at an estimated cost of approximately $400 million.

The new TB2 Terminal 2 complex is composed of 4 separate blocks. These are identified as Block A, Block B, Bridge, and Block C which is the concourse building.

Figure 1. Layout Of The Terminal 2 Complex And Bridge Block In It.

The bridge structure is composed of two separate blocks. The location of expansion joint is selected considering the geometrical properties of the structure along its length. The block above the parking lot is essentially rests on “shorter” columns due to the absence of Baggage Handling System. This part is identified as having only one basement floor which is called First Basement. The block above BHS area is slightly more complicated since it accommodates two floors below. First Basement Floor continues as Baggage Handling Floor and underneath, Second Basement Floor, accommodates Back of the house operations for Baggage Handling System, which is designed by Dutch firm Van Der Lende.

Bridge Structure is typically a structure composed of an only deck floor with foundation level at +7.30 and deck level at +14.60 between A013 and A12 axis and foundation level of +2.90 with the deck level at +14.60 and an additional composite BHS floor between Axis A12 and A204. The structure is bounded with Block A and Bock B at both long ends due to the nature of master plan. Basement-2 floor consists of slab on grade which rests on structural fill.

Basement-1 floor consist of composite floor system supported by steel beams. Bridge Deck is composed of Reinforced Concrete slab which are resting on Reinforce Concrete main girders.

For design and calculation SI units and derived units are used.

Figure 2. View from the Bridge

Analyses and Design Assumptions

Analyses Model

The analysis of the structure is carried out using general finite element software SAP 2000 V14.2.4.The structural analyses and design results are included in this section. The software utilizes the finite element method for 3D analysis. Columns and beams of the building are represented as "frame" elements while the walls are modelled as "plate" elements. Analysis Models are created without slabs elements. Slabs self-weight loads and additional dead load, live loads and traffic loads are distributed on frame elements to afford unfavorable condition.

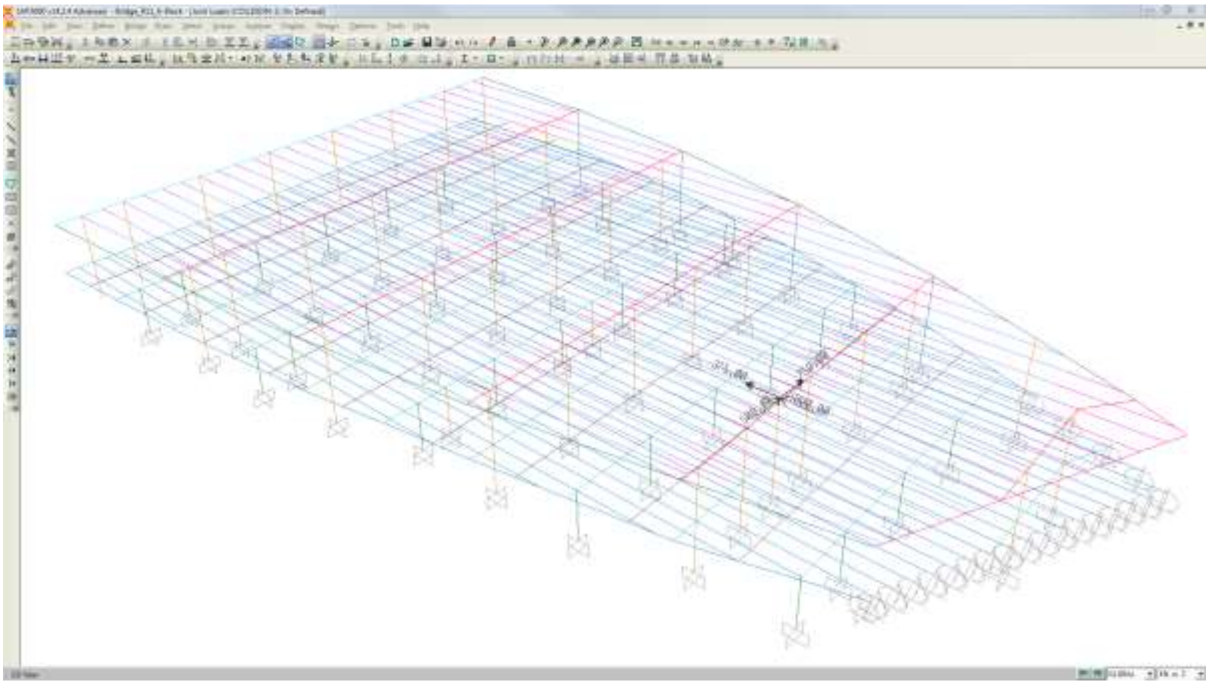

Figure 5. 3D View of Structural Analyses Model A

Dead Loads

Dead load is the self-weight of the reinforced concrete members of the structure. In the structural analysis, self-weight of the monolithic reinforced concrete members such as columns, girders, slabs are calculated automatically by the SAP 2000 V14.2.4 software.

Superimposed Dead Loads

Structural superimposed dead loads on bridges are utilized in accordance with Chapter (5) of the associated Egyptian Code in accordance with Part D, Item 1 of Tender Drawing S-00-001, and respective “General Notes”. Super imposed dead loads on bridges are for roadway areas 2.20 kN/m^2 and for walkway areas 4.00 kN/m^2 due to the additional concrete fill to establish pavements on the bridge deck.

Live Loads

Assembly Area

For the Deck floor, 5.00 kN/m^2 live load is considered. This load is defined as distributed load on main frames and on shell elements.

Truck Loads

According to EN 1991-2, Load Model-1 vehicles are taken from the following table. From this table vehicle having 600 kN weight will be used in the analysis. Furthermore as described in the project general notes and the design criteria, the related code for application of traffic loads is derived using Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges. The following illustration describes the application methodology of the traffic loading;

Table 1. Load Model 1: Characteristic Values

Location	Tandem TS	UDL System
	Axle Loads Q_a (kN)	q_a (kN/m^2)
Lane Number 1	300	9
Lane Number 2	200	2,5
Lane Number 3	100	2,5
Other Lanes	0	2,5
Remaining area	0	2,5

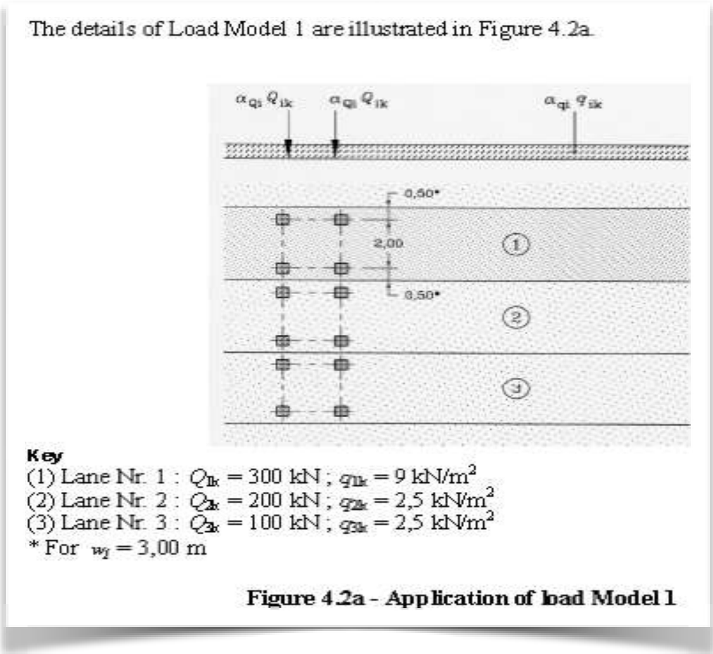

Figure xx. Load Model 1 Application Scheme

Partial load factors and load combinations of safety in design of bridge elements followed BS EN 1990:2002. Although the bridge shall not be utilized entirely for traffic, it is assumed that entire bridge is composed of traffic lanes. According to Eurocode figure above, each lane width is 3m. However, beams are placed at 2.7m intervals in the structural model. In order to be clear in the model and eliminate the use of fictive members each beam is assumed to carry one lane. Therefore 24 lanes are defined in the model. These 24 lanes are grouped in 3 lanes that form Traffic Lanes (TL) as shown in Figure XX.

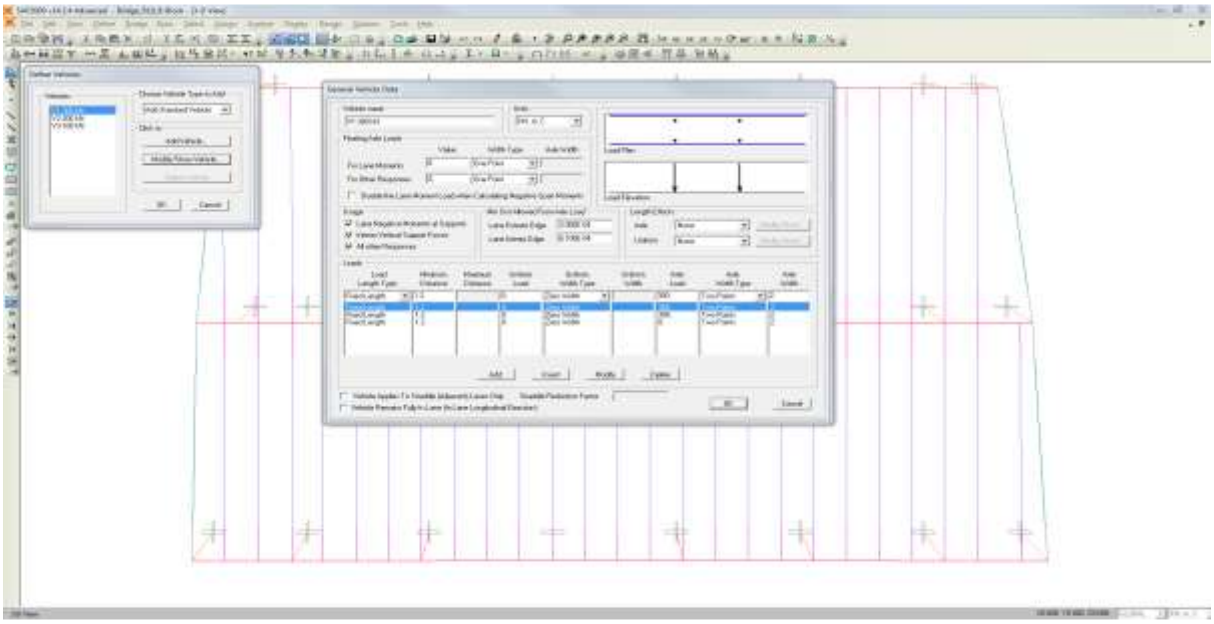

Figure xx. 300 kN Vehicle Definition on SAP2000 with Moving Load Case

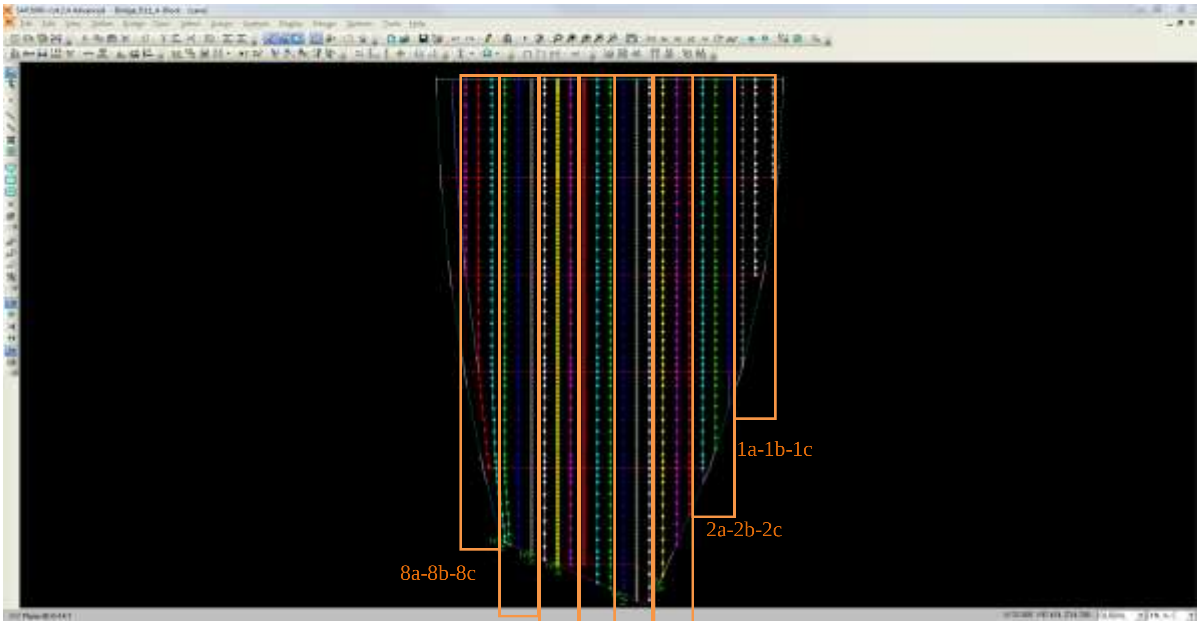

Figure xx. Lane Definition

Each TL group are composed of 3 different Vehicle loads assigned to each lane, that are identified as the indices a, b and c. For example TL-1 lane is composed of Lane 1a, 1b and 1c as shown below. Lane 1a is loaded with 300kN vehicle which is defined as Vehicle 1, Lane 2a is loaded with 200 kN vehicle which is defined as Vehicle 2 and Lane 1c is loaded with 100kN vehicle which is defined as Vehicle 3. Uniform Distributed loads are not defined within the Vehicle Load Case since they are represented separately on to the frames. Distributed Lane Load value defined by the code is 9.00 kN/m^2 for lane having 300 kN Vehicle and 3 meter width. Since the interval of longitudinal beams is 2.70 meter the uniform load values is derived and applied as 9.00 kN/m^2 x (3.00/2.70) = 10 kN/m^2 . The uniform load on beams is calculated as 10 kN/m^2 x 2.70 = 27 kN/m. The uniform load applied on the rest of the lanes is calculated as 2,5 kN/m^2 x 3.00 = 27 kN/m.

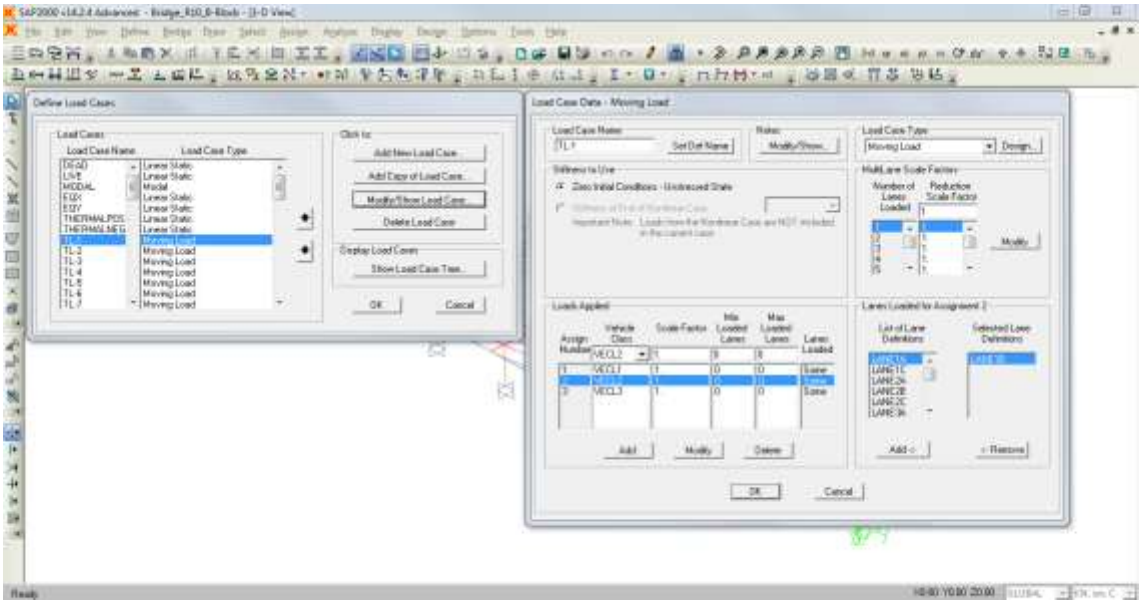

Figure xx. Lane Assignments of Moving Load (Vehicle 2 is shown, Vehicles 1 and 3 similar)

When applying these loads into the load model, several approaches are developed. The UDL that is applied on to the beams are classified and defined in the load combinations in three different ways. The first, all of the beams are loaded with live load in order to find the maximum shears in the slab system. The other two is applied as a checkerboard way, one span loaded one span empty, and vice versa.

Other Loads

We have applied several other loading conditions specific to the bridge structure.

- Thermal Load; Thermal loads have been applied via two separate Load Cases: thermal negative being -20 ^{0}C and thermal positive +20 ^{0}C
- Breaking Force; Breaking forces are calculated according to Eurocode 1 Part 2 Section 4.4.1. This force is applied on the Main Beams at each axis along the Lane direction, as a separate Load Case.
- Canopy and Collision Load; There is a Canopy above the bridge deck that needs to be supported by some of the bridge columns. The entire canopy is a steel structure and designed by a different group. Therefore Loads of this canopy is applied case by case as a point load at each of its application point. Also due to geometry of the canopy, bridge columns that support canopy needed to be extended approximately 1m above the deck level. Therefore a vehicle collusion Load is applied in the model to these locations.
- Settlement; although the foundations of the structure is resting on piles, since footings are pad footings rather than raft footing, we have established a settlement load case. We have applied 1cm settlement in the model under each column at a certain axis. Each axis settlements are defined as a separate load case and these are entered in the combinations separately.
- Earthquake Loads; Earthquake loads are calculated with modal response spectrum

analysis automatically by SAP 2000 V14.2.4 according to EN-1998:2004 using the following parameters.

Table 1. Seismic Design Parameters (According to EN-1998:2004)

Seismic Design Parameters (According to EN-1998:2004)	
Elastic Response Spectra	Type 2
Importance Factor	1.4
Ground Type	C
Design Ground Acceleration (Ag)	0.15g
Behaviour Factor (q)	3/2/1.5

Foundations

The tender design foundation scheme consisted very large bulk concrete cube blocks of 3mx3mx3m under the single footings. We believe concept designer used such a system because it was a well-known method of foundation construction in desert environment in Egypt. This type of foundation is became known as "Alexandria Foundation". However we believed that instead of these large blocks we should apply Cast in Place piles under the single footings. Therefore foundation system of the bridge consists of single footings resting on piles. Maximum pile axial load capacity for Ø800 with 16 m length is given as 3000 kN in Confirmatory Geotechnical Site Investigation Report Building A, Main Bridge and Building C. For limiting the group settlement to 25 mm, reduction factor 1.20 has been advised. Finally pile axial load capacity is considered as 2500 kN. Also a tie beam arrangement between single footings is also provided for the foundation scheme.

The bridge analyses model is established so that each footing is modelled with its real time piles. Piles are represented as springs. The spring constant is calculated as

$$[K] = \{F\}/\{d\} \qquad (1)$$

K, the spring constant, F is the pile capacity and d is the maximum allowed settlement value. The spring constant becomes 250ton/25mm = 100 t/cm.

Through the structure due to the geometry and loads several different iterations of pile and pile cap arrangements are used. Under the abutments, strip foundations are utilized. Piles are designed and spaced according to the structural analyses results. These analyses resulted in 80cm diameter piles along edges and 60cm diameter piles along the middle parts of pile caps.

Slab on Grade

Ground slab is resting on the grade with isolation joints at column locations and does not transfer any vertical or horizontal load to the columns. Concrete slab on grade has no effect in structural behavior of building and it is not included in the structural model. However since the area is geometrically and architecturally complicated, area needed to be studied carefully. Many elevation differences and ramps occur where need to be accommodated in drawings.

Columns

Columns are spaced at approximately 21.60 m intervals in both directions of building. In the BHS area however, further Steel Columns are added every other axis making the effective spacing of columns 10.8m. 1m x 1m square columns are used although on a few locations columns are dimensioned as 90cm x 90 cm due to architectural reasons.

Ground Floor System

The bridge ground floor system is composed of Cast in Place Beams of two types. First type is identified as Main Beams which lay transversely along the short direction of the bridge. Their span varies between 10-12m. At several axis edges they are cantilevering in order to accommodate the unique form and interface with adjacent blocks. Although due to their varying locations and loading conditions size of main beams are kept typical 120cm wide by 140cm deep and the design is detailed in the reinforcement.

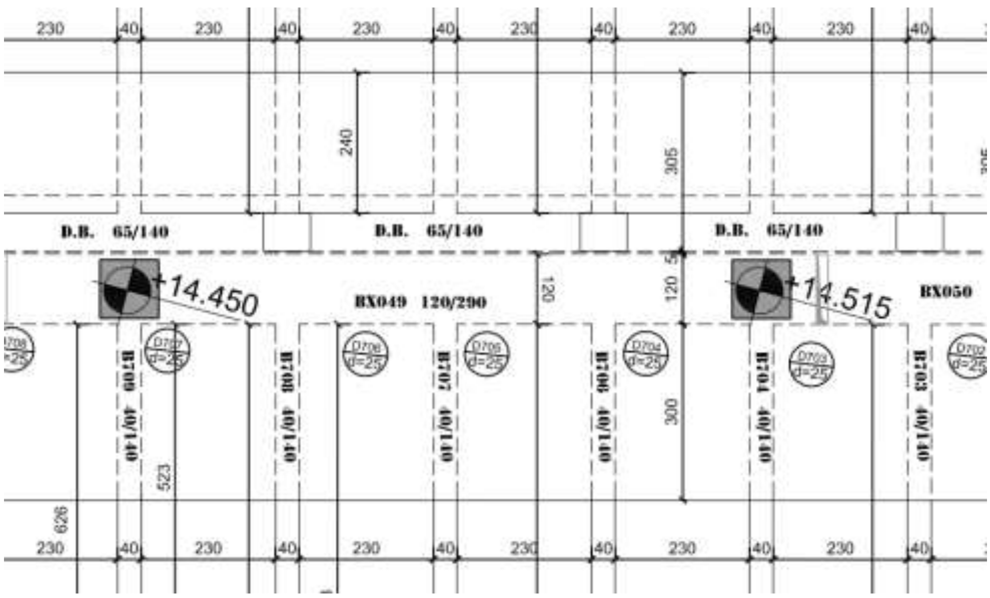

Figure xx. A12 Axis Layout

The ground floor is composed of two main blocks that are separated by an expansion joint located at A12 axis. Expansion joint placed approximately at the middle of the complete length. A12 axis main beam is the beam that accommodates the expansion joint.

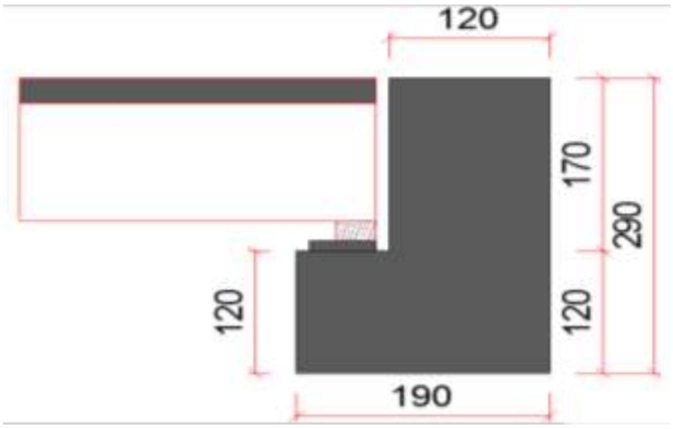

Figure xx. A12 Axis Beam Cross Section

In order to accurately design the expansion joint beam and its ledge, we have utilized both models. First, in Block A structural model, we have read the support reactions assigned to bearing locations. Since the program works with the joints that are defined at the center of members, in Block B structural model, we have defined fictive rigid cantilevering frame elements at these bearing locations in order to represent the eccentricity effect at the ledge.

Second type is identified as the secondary beams. These beams also grouped according to their locations such as interior span and exterior span. Other than expansion joint location, secondary beams are designed as continuous spans. Continuity helps the design in terms of lowering the midspan moments and deflections however costs very high support moments. Since beam depths and widths could not be revised due to administrative purposes, an unusual design option is applied.

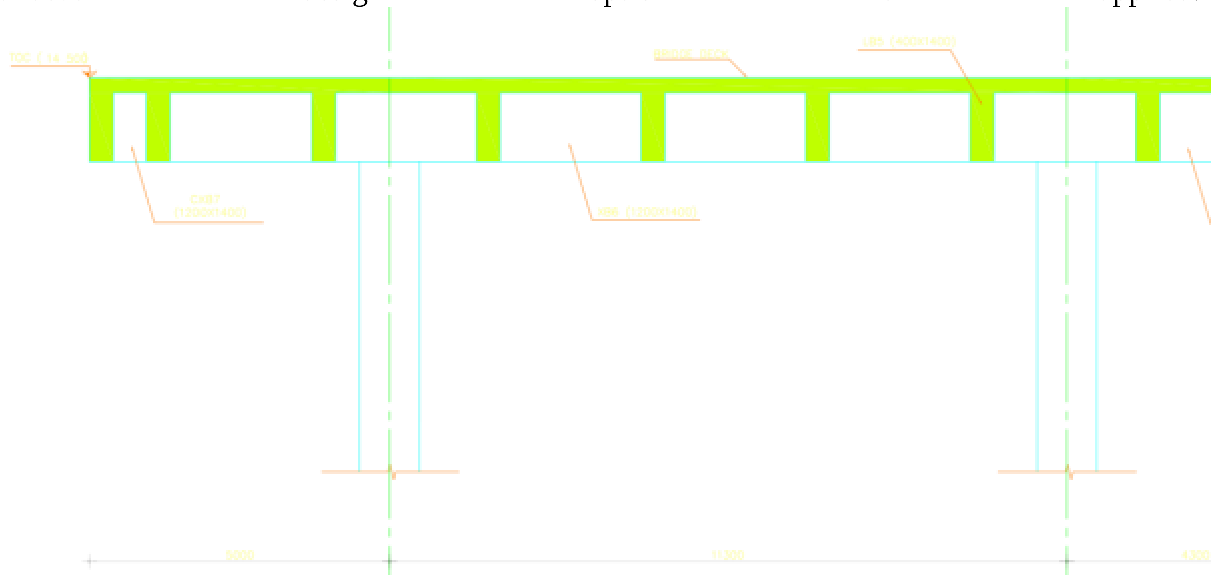

Figure xx. Typical Cross Section at Midspan

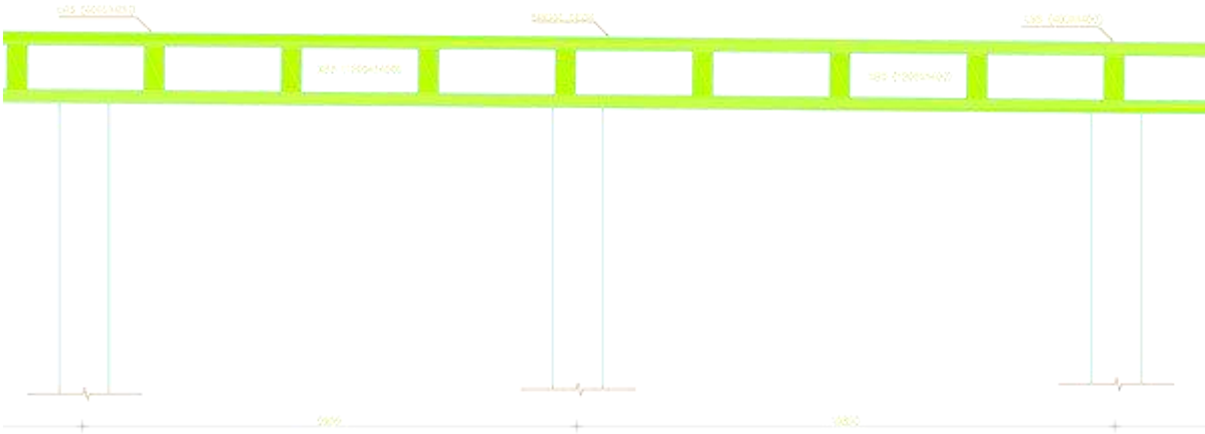

Figure xx.   Typical Cross Section at Support

In order to take into consideration the effect under compression, a slab at the bottom of the beams that is 3m wide towards each span is applied. With the help of this bottom slab, 40x140cm beams could be designed at support locations.

Conclusions

Both Airport Bridge specific and cast in place concrete bridge specific solutions applied in this project represent both challenges and opportunities. It proves once again that old fashioned design methodologies ca be blended into the modern construction materials and methods within challenging architectural functions. The fact that cast in place concrete bridge is used allowed us more freedom to adapt existing structures into the architectural design. This creates opportunities and options to bridge engineers depending on availability of precast or steel bridges. Furthermore since it is more common to design with cast in place concrete in the Middle East therefore contractors are very well prepared and knowledgeable with this type of construction.

On the other side, interim down side of cast in place concrete construction displayed themselves in every step of construction such as formwork and falsework necessities. Also the effect on construction sequence needs to be coordinated well ahead of time in order to prevent its negative impact to the overall construction schedule.

Acknowledgments

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