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Dynamic response and structural safety of a segmental precast concrete box-girder bridge during construction

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ABSTRACT

The dynamic response and structural safety of a segmental precast concrete box-girder bridge during construction are investigated. The bridge is realized by means of a balanced cantilever approach where bridge segments are sequentially erected to form deck spans counterweighted about a single support. The segments are precast at the ground level, uplifted up to the deck level, and moved to the final location at the end of the cantilever arms. The results of structural analyses carried out to investigate the dynamic response of the bridge during the construction process show that a bridge failure with overturning of the cantilever arms may occur if the dynamic effects are not properly considered.

1. INTRODUCTION

Segmental concrete box-girder bridges are often realized by using a balanced cantilever approach where individual bridge segments are sequentially erected to form individual deck spans counterweighted about a single support (Mathivat 1983, AASHTO – PCI – ASBI 2002). The segments are kept in the cantilever arms together by means of post-tensioning of longitudinal prestressing tendons. During the erection stage the superstructure must be connected to the piers through suitable anchoring systems. Usually the superstructure is made stable by using prestressing cables or prestressed bars which clamp the head deck segment to the top of the pier. This link must sustain the possible unbalances between the two cantilevers and may be critical if the cables or the bars are too weak or if the unbalance becomes excessive.

For precast construction, the precast bridge segments are uplifted from the ground up to the deck level and moved to the final location at the end of the cantilever arms. Depending of the employed equipments, the uplift and movement in place of the deck segments may involve significant dynamic effects in the bridge structural response, with important accelerations and inertia forces. These forces need to be properly taken into account to ensure a suitable level of structural safety during the construction process.

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The dynamic response and structural safety of a segmental precast concrete box-girder bridge during construction are investigated in this paper. The results of structural analyses carried out to investigate the dynamic response of the bridge during the construction process show that a bridge failure with overturning of the cantilever arms may occur if the dynamic effects are not properly considered.

2. DESCRIPTION OF THE BRIDGE AND CONSTRUCTION PROCESS

A three-span segmental precast concrete box-girder bridge with span lengths 50 + 90 + 50 m is considered. Figure 1 shows the erection scheme based on a balanced cantilever approach to form deck spans counterweighted about a single pier.

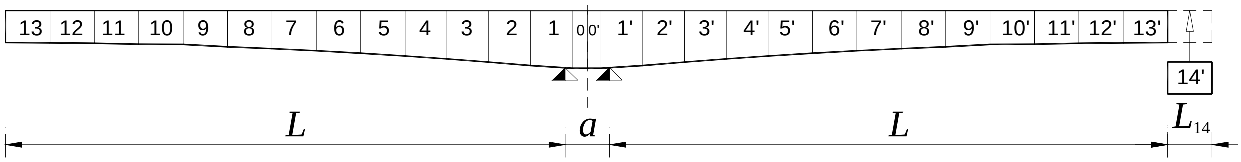


Fig. 1 Erection scheme to form deck spans counterweighted about a single pier for a three-span segmental precast concrete box-girder bridge

The precast bridge segments are uplifted from the ground up to the deck level and moved to the final location at the end of the cantilever arms by using a moveable formwork. The segments are kept in the cantilever arms together by means of post-tensioning of longitudinal prestressing tendons. In this way, the segments 1 to 13 and 1' to 13' are cantilevered over a length L = 44.53 m from each side of the pier in a balanced sequence until midspan is reached. At each abutment, two end-span segments 14' and 15' with length L_{14} = 3,40 m are then assembled on temporary false-work to minimize the unbalanced moment. A cast-in-place closure segment at midspan is finally realized.

During the erection stage the superstructure is connected to each pier through two temporary anchor systems with lever arm a = 3,40 m. Each anchoring system is made by a set of Dywidag steel bars with total nominal strength T = 5,26 MN. The weight of the bridge segments are listed in Table 1. The weight of the moveable formwork is P_c = 550 kN. The supporting cables of the moveable formwork consist of 16 steel cables with diameter $\varnothing$ = 20 mm.

Table 1 Weight of the bridge segments

Segment i	0+1	2	3	4	5	6	7	8	9	10	11	12	13	14-15
Weight P_i [kN]	1250	760	725	680	690	645	627.5	600	587.5	557.5	545	532.5	530	530

3. PROBLEM STATEMENT

By denoting R_{1max} the maximum value of the uplift reaction force at the temporary anchor steel bars at the erection stage, the following condition must be verified to avoid bridge failure with overturning of the cantilever arms (Fig. 2):

$$R_{1max} \leq T \tag{1}$$

In practice, during construction of the bridge it was considered the possibility to erect the end-span bridge segment 14’ by avoiding the use of false-work. In fact, based on the structural scheme shown in Fig. 2, the following static reaction forces were evaluated at anchor bars:

$$R_{10} = R_{1max} = 5{,}14 \text{ MN} < T = 5{,}26 \text{ MN} \tag{2}$$

$$R_{20} = 23{,}68 \text{ MN} \tag{3}$$

However, the uplift of the end-span deck segment 14’ may involve dynamic effects in the structural response of the bridge, with time-variant reaction forces $R_1 = R_1(t)$ and $R_2 = R_2(t)$. Therefore, the very narrow safety factor $\psi = T/R_{1max} = 1.02$ cannot ensure a suitable level of structural safety of the bridge during the constructions process. The results of time-history dynamic analyses are presented in the following to show that the dynamic effects due to erection of segment 14’ may lead to a bridge failure with overturning of the cantilever arms.

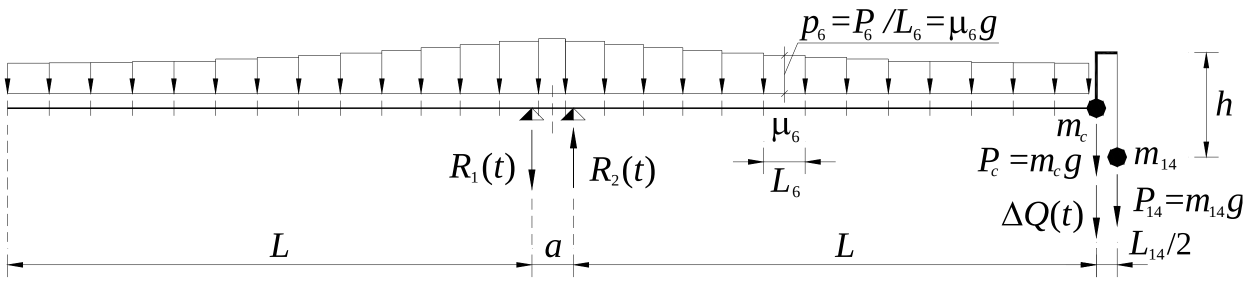


Fig 2 Structural model of the bridge during erection of bridge segment 14’

4. STRUCTURAL MODELING

The structural model shown in Fig. 2 is considered. Linear elastic behavior up to failure of the temporary anchor steel bars is assumed, with elastic moduli E_c = 30 GPa and E_s = 200 GPa for concrete and steel cables, respectively. The uplift of the segment 14’ starts when the segment is located at the end span below the deck profile. The free length of the steel cables at power up of the lifting equipment is h = 8.55 m. Based on the engine specifications and winch arrangement, the maximum value of the transient force exerted by the lifting equipment at power up is Q_{max} = 3,06 MN. Therefore, considering the weight P_{14} = 530 kN of the bridge segment 14', the maximum value of the unbalanced force $\Delta Q(\mathrm{t}) = [Q(t) - P_{14}]$ at power up is

$$\Delta Q_{\max} = Q_{\max} - P_{14} = 2{,}53 \text{ MN} \tag{4}$$

The time function shown in Fig. 3 is assumed for the transient unbalanced lifting force $\Delta Q = \Delta Q(t)$. By denoting Q_m the mean value of the transient lifting force

$$Q_m = P_{14} + \Delta Q_{\max}(\mathrm{t_0}-\mathrm{t_a})/\mathrm{t_0} = P_{14} + (Q_{\max} - P_{14})(t_0 - \mathrm{t_a})/t_0 \tag{5}$$

and by introducing the engine design requirement $Q_m = 0.85Q_{\max}$

$$P_{14} + (Q_{\max} - P_{14})(t_0 - t_a)/t_0 = 0.85Q_{\max} \tag{6}$$

the duration t_a of the impulse ramps is estimated as follows

$$t_a = [0.15/(1 - P_{14}/Q_{\max})]\ t_0 \cong 0.181t_0 \tag{7}$$

An approximate value of the ramp duration t_0 = 0.05 sec can also be estimated based on the characteristics of the engines of the lifting equipment. However, the parameter t_0 may vary around this value with significant uncertainty. A range of values needs then to be considered to investigate the dynamic response of the bridge during erection.

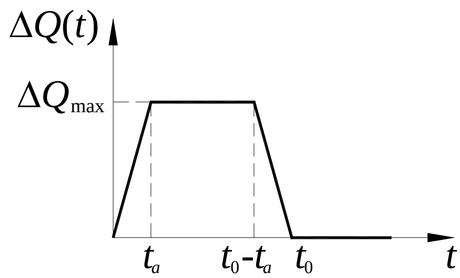
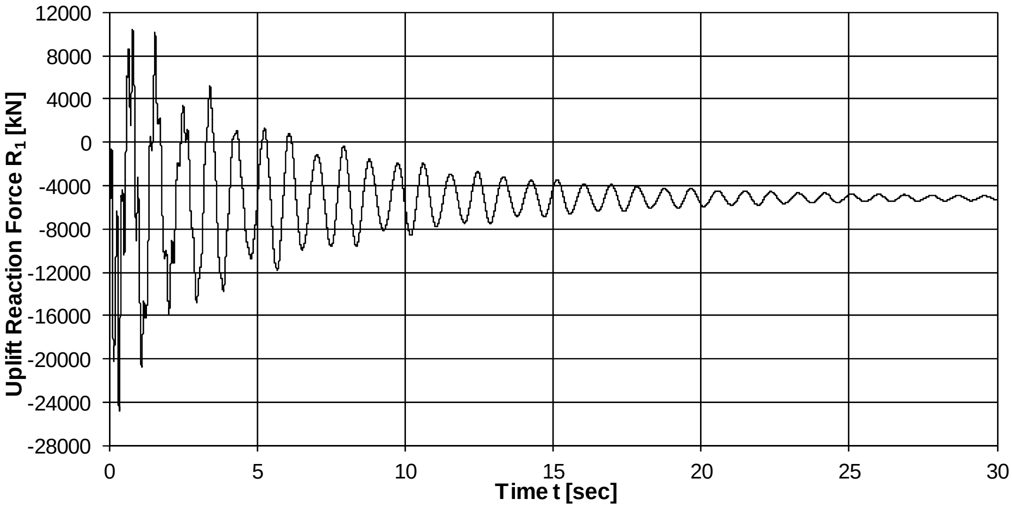


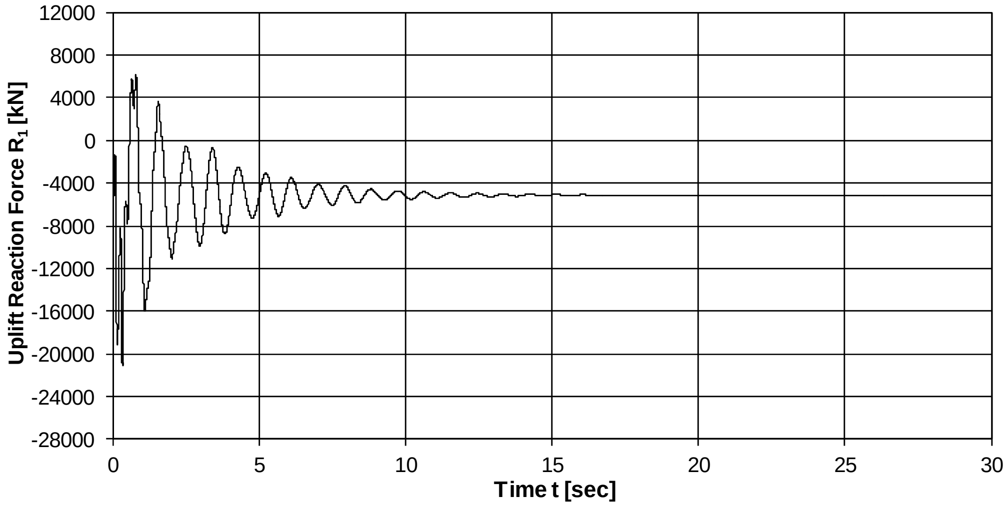
Fig. 3 Model of the transient force exerted at power up of the lifting equipment

5. TIME-HISTORY DYNAMIC ANALYSES

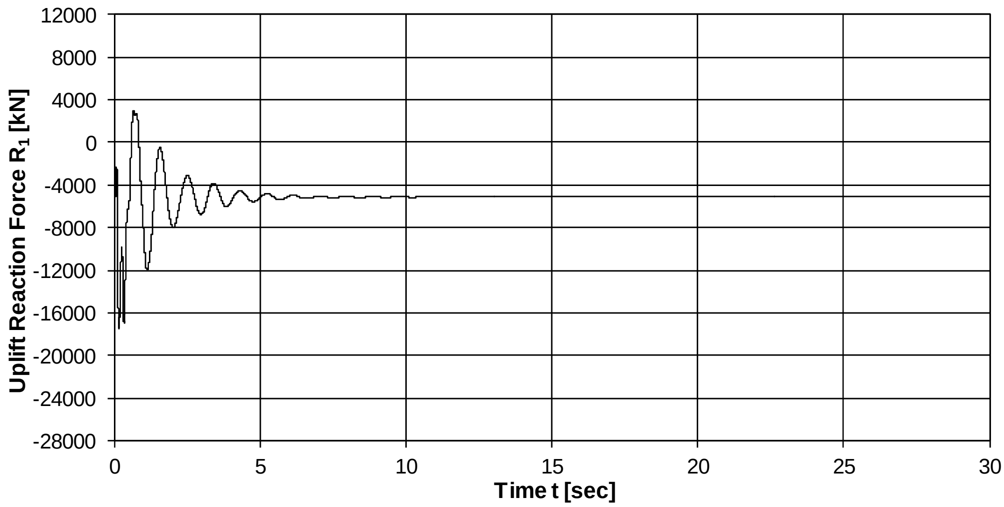
The dynamic response of the bridge during erection of segment 14' depends on uncertain parameters, such as the ramp time interval t_0 and the structural damping ratio ξ. A parametric investigation is carried out to investigate the role of these quantities by assuming t_0 = 0.100, 0.050, 0.020, 0.010, 0.005 sec and ξ = 2%, 5%, 10%. Fig. 4 shows the time evolution of the uplift reaction force $R_1 = R_1(t)$ obtained for t_0 = 0.05 sec by time-history dynamic analyses carried out on the structural model shown in Fig. 2. The results for all cases studied are listed in Table 2 in terms of maximum reaction force $R_{1\max} = \max R_1(t)$, dynamic amplification factor $\varphi = R_{1\max}/R_{10}$, and safety factor $\psi = T/R_{1\max}$.



(a)



(b)



(c)

Fig. 4 Reaction force $R_1 = R_1(t)$ for t_0=0.05sec: (a) ξ = 2%; (b) ξ = 5%; (c) ξ = 10%

Table 2 Results of time-history dynamic analyses in terms of maximum reaction

t_0	R_{1max} [MN]			$\varphi = R_{1max} / R_{10}$			$\psi = T / R_{1max}$		
[sec]	ξ = 2%	ξ = 5%	ξ = 10%	ξ = 2%	ξ = 5%	ξ = 10%	ξ = 2%	ξ = 5%	ξ = 10%
0.100	37.97	32.31	27.85	7.39	6.29	5.42	0.14	0.16	0.19
0.050	24.81	21.05	17.48	4.83	4.10	3.40	0.21	0.25	0.30
0.020	13.48	11.81	10.17	2.62	2.30	1.98	0.39	0.45	0.52
0.010	9.35	8.50	7.66	1.82	1.65	1.49	0.56	0.62	0.69
0.005	7.25	6.82	6.40	1.41	1.33	1.25	0.73	0.77	0.82

force $R_{1max} = \max R_1(t)$, dynamic amplification factor $\varphi = R_{1max}/R_{10}$, and safety factor $\psi = T/R_{1max}$.

6. RESULTS AND CONCLUDING REMARKS

The results of parametric time-history dynamic analyses demonstrate that the uplift of the end-span deck segment 14' involves significant dynamic effects in the structural response of the bridge, with maximum uplift reaction forces R_{1max} sensibly higher than the nominal strength T of the anchoring steel bars. As a consequence, a bridge failure with overturning of the cantilever arms is expected to occur in case false-work is not used to realize the end-span deck segments. A proper assessment of the dynamic effects is therefore of major importance to ensure structural safety during construction of segmental concrete box-girder bridges erected by a balanced cantilever approach.

REFERENCES

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