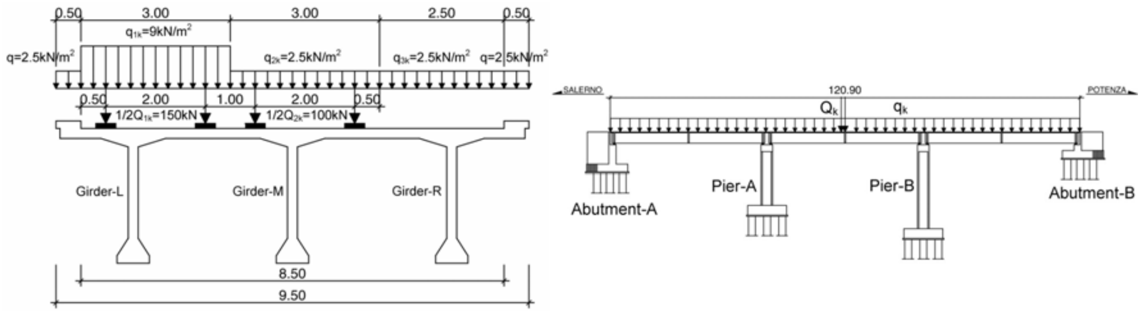
According to the comparisons between original code DM 1990 and updated code NTC2008, it could be found that the influence under static loads combination in NTC 2008 is slightly smaller than that in DM 1990 and the gap less than 10%; however, the influence under highway live load and response spectrum in NTC 2008 is larger than that in the original codes, which are 20~30% and 70~80%, respectively. Consequently, the NTC 2008 could be chosen as the design code in this paper. According to NTC 2008, two load lines could be arranged with the width of 3×2=6m. The width of remaining area is 2.5m. The crowd load could be applied to both footpaths with each 0.5m wide. Similar to the DM 1990, the typical asymmetrical arrangement of traffic load lines and crowd load lines in the transverse direction is illustrated in Figure 12(a), which can be also used to consider the most unfavorable loading state for Girder-L. In the longitudinal direction, the concentrate loads can move along the whole superstructure length and the distributed loads (q_{ik}) could be applied to the whole superstructure length. The arrangement of traffic loads in longitudinal direction is shown in Figure 12(b).



(a) Transverse direction (b) Longitudinal direction

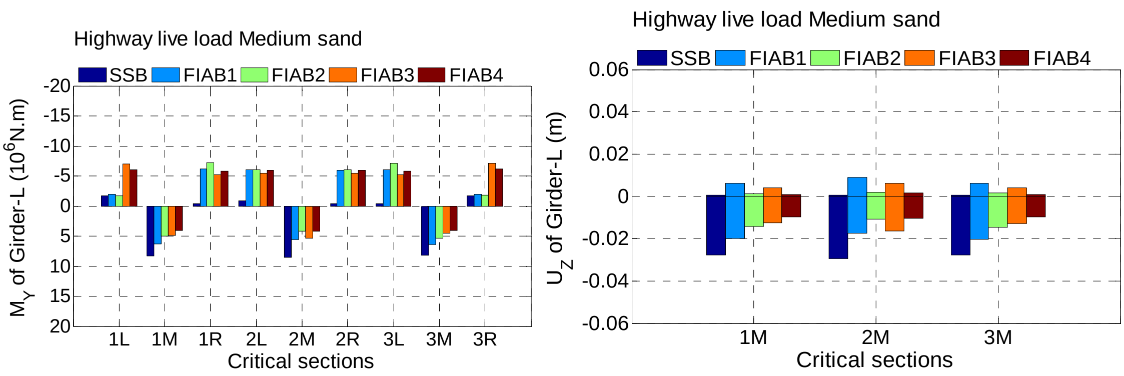
Figure 12. Arrangement of highway live load in NTC 2008.

For the M_Y of girders under highway live load (Figure 13 (a)), the retrofit with the FIAB concept could reduce the positive M_Y at the mid-span points of each span. However, these retrofitting approaches increase the unfavorable negative M_Y at the both girder ends of each span. Considering the critical sections near abutments ($C_{S\text{-}1L}$ and $C_{S\text{-}3R}$), the M_Y of girders in FIAB3 and FIAB4 after retrofitting are larger than those in FIAB1 and FIAB2. Moreover, considering the critical sections near piers ($C_{S\text{-}1R}$, $C_{S\text{-}2L}$, $C_{S\text{-}2R}$ and $C_{S\text{-}3L}$), all the retrofitting methods increase the M_Y of girders subjected to highway live load a lot. The U_Z at the mid-span points of each span in SSB under highway live load could be reduced through retrofitting, as illustrated in Figure 13 (b).

The M_Y at the top and bottom points of two piers in different bridge types under highway live load are compared in Figure 14. It could be observed that the M_Y at the top of piers in FIAB2 and FIAB4 are larger than those in FIAB1 and FIAB3.

The M_Y at the top points of abutment stems ($C_{A\text{-}T}$) in different bridge types under highway live load are compared in Figure 15. It could be observed that the M_Y at the top points of abutment stems in FIAB3 and FIAB4 under highway live load are larger than those in FIAB1 and FIAB2.

Under highway live load, the M_Y of piles in all bridge types are quite small and the result is not presented here.



(a) M_Y of Girder-L (b) U_Z of Girder-L

Figure 13. Influence of different bridge types on girder under highway live load

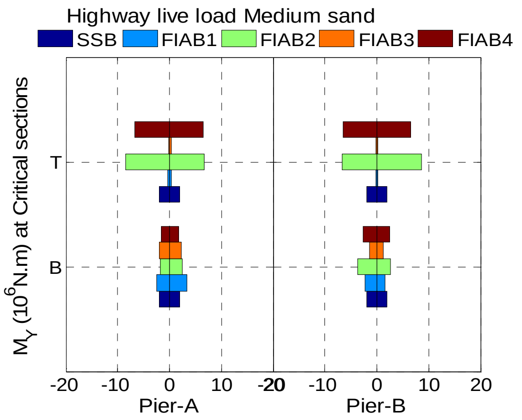


Figure 14. Influence on pier

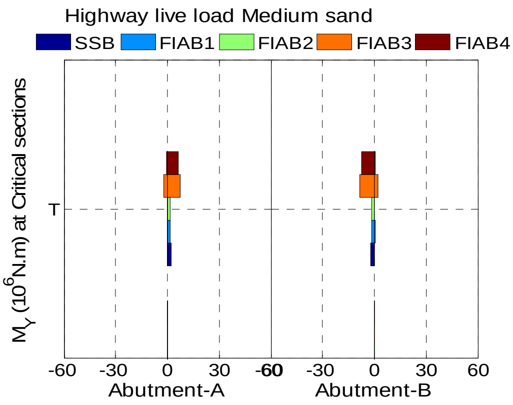


Figure 15. Influence on abutment

Influence of substructure height

In this section, the heights of piers and abutments (including the backwall and stem) are chosen as the parameters. Based on two pier heights in real case (13.7m and 19.7m), another two assumed values (7.7m and 25.7m) were chosen. These four heights could form an arithmetic sequence and cover the range of pier heights in normal cases. For the abutment heights, two values in real case (4.5m and 8m) were taken into account, which could cover the range of abutment heights in normal cases. Based on these assumptions, fifteen cases, including fourteen idealized cases and one real case, as listed in Table II, could be used to investigate the influence of substructure heights.

TABLE II. RESEARCH CASES

	Column	1	2	3	4	5
Row	Case	H_{PA}= H_{PB} =7.7	H_{PA}= H_{PB} =13.7	H_{PA}= H_{PB} =19.7	H_{PA}= H_{PB} =25.7	H_{PA}=13.7 H_{PB}=19.7
1	H_{AA}=H_{AB}=4.5	a4.5p7.7	a4.5p13.7	a4.5p19.7	a4.5p25.7	a4.5pReal
2	H_{AA}=H_{AB}=8	a8p7.7	a8p13.7	a8p19.7	a8p25.7	a8pReal
3	H_{AA}=8 H_{AB}=4.5	aRealp7.7	aRealp13.7	aRealp19.7	aRealp25.7	Real case

H_{PA} means the height of Pier-A; H_{PB} means the height of Pier-B; H_{AA} means the height of Abutment-A; H_{AB} means the height of Abutment-B; Real means that the heights of piers and abutments are the same as those in 'Viadotto Serrone'

By analyze the results illustrated in Figure 16, it could be found that the influence of different pier heights on the performance of Pier-A in FIABs under thermal load is significant. Considering the cases that have equal pier heights (‘a4.5p7.7’, ‘a4.5p13.7’, ‘a4.5p19.7’ and ‘a4.5p25.7’), with the pier heights increase, the F_{SX} of piers decrease; however, the displacement in longitudinal direction (U_X) of piers increase. The M_Y of piers could be divided into two conditions corresponding to different types of superstructure-pier connections. For FIAB1 and FIAB3 that have hinged superstructure-pier connections, the M_Y of piers decrease with the pier heights increase. For FIAB2 and FIAB4 that have rigid superstructure-pier connections, with the pier heights increase, the M_Y at the bottom of piers decrease, while, the M_Y at the top of piers increase. By comparison, it could be found that the influence of different pier heights on the performance of abutment stems under thermal load is negligible.

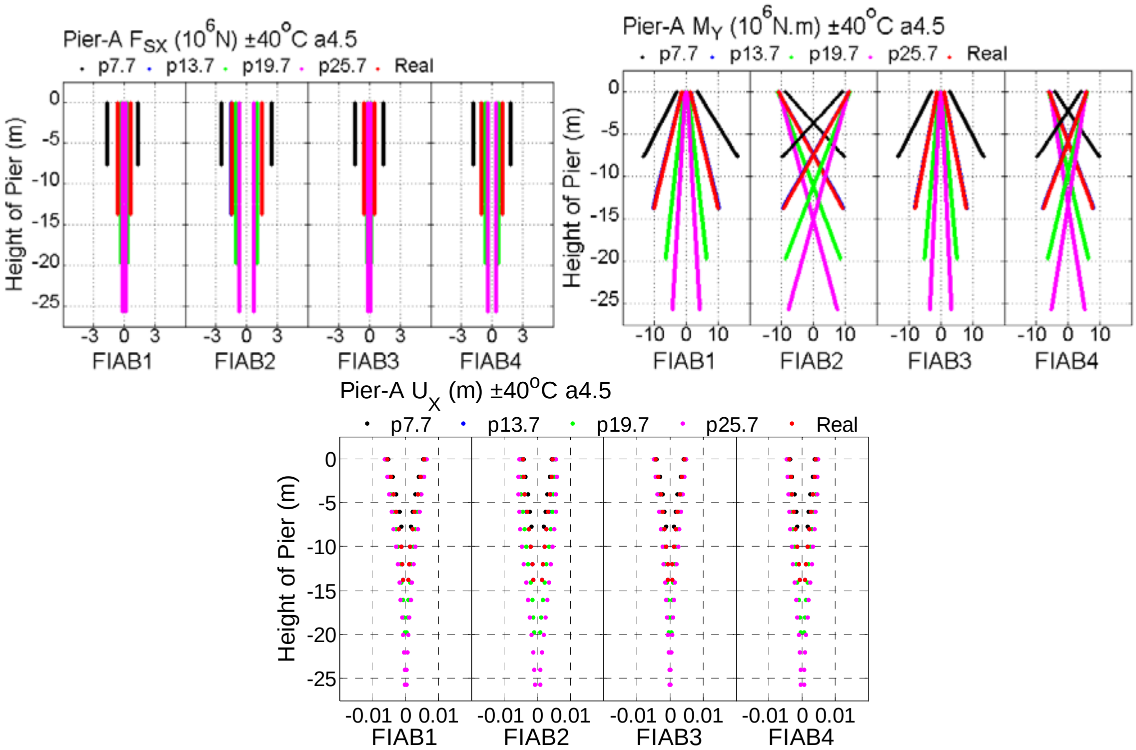


Figure 16. Influence of different pier heights on the performance of pier under thermal load.

The influence of different abutment heights on the performance of Abutment-A stem in FIABs under thermal load is illustrated in Figure 17. By comparing ‘a4.5p7.7’ and ‘a8p7.7’, it could be found that the effect of different abutment heights on the performance of abutment stems is significant. With the abutment heights increase, the F_{SX} of abutment stems decrease; however, the U_X and M_Y of abutment stems increase.

The influence of different abutment heights on the performance of Pile-5 beneath Abutment-A in FIABs under thermal load is illustrated in Figure 18. By comparing ‘a4.5p7.7’ and ‘a8p7.7’, it could be found that under thermal load, the effect of different abutment heights on the performance of piles beneath abutments is significant. The F_{SX}, M_Y and U_X of piles beneath abutments would decrease with the abutment heights increase.

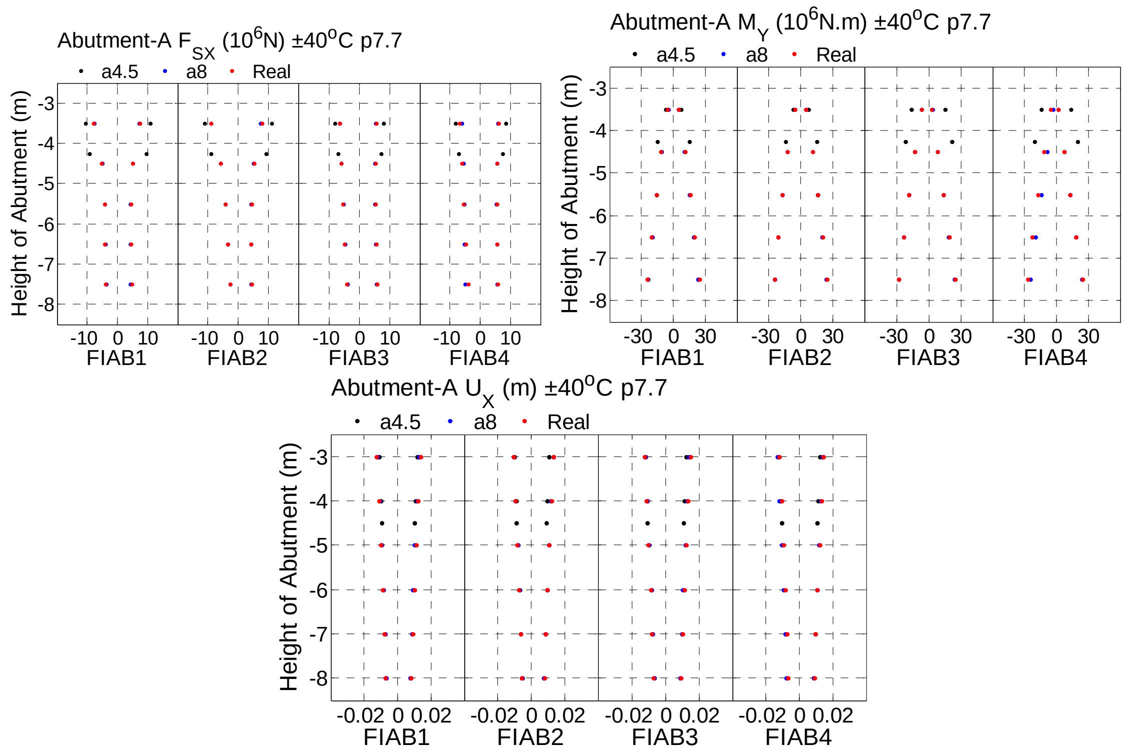


Figure 17. Influence of different abutment heights on the performance of Abutment-A stem under thermal load.

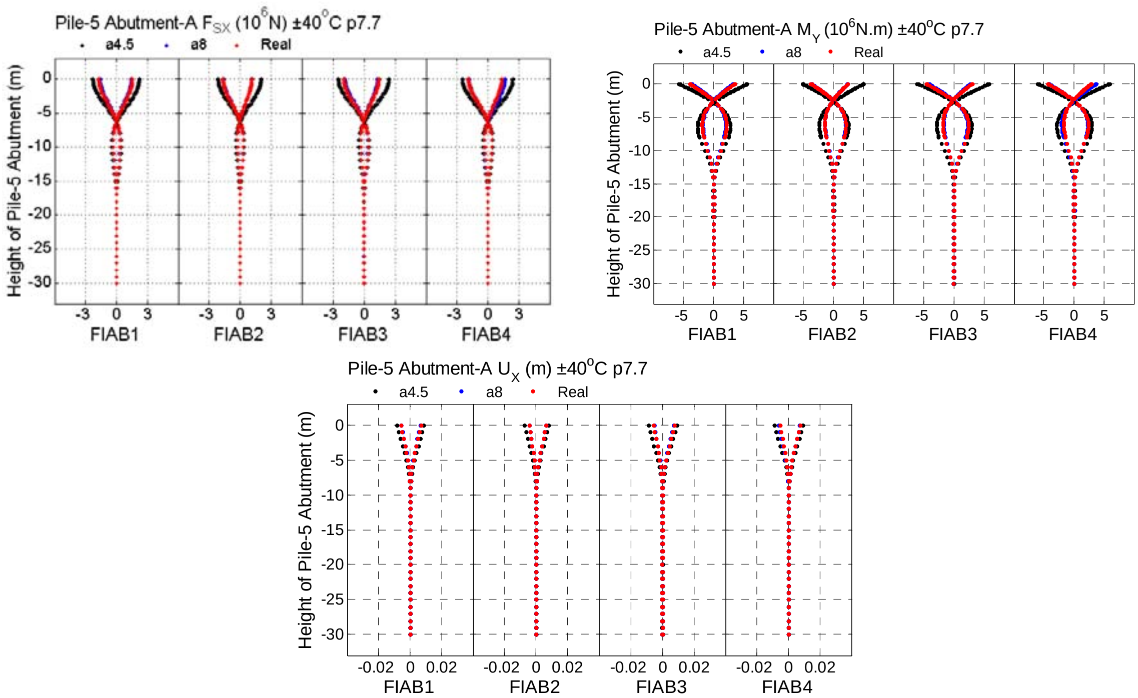


Figure 18. Influence of different abutment heights on the performance of Pile-5 beneath Abutment-A under thermal load.

CONCLUSIONS

In this paper, assuming the soil type as medium sand, the influence of different substructure heights on the performance of different types of FIABs under thermal load is analyzed. Some regulations are listed as following.

(1) Due to the advantages in terms of life-cycle costs, durability, enhanced structural response and ease of maintenance, the IAB's concept can be fruit-fully applied in the retrofitting process of existing simply supported bridge.

(2) From the knowledge and experience of the author and from the case study, it is proved that the introduction of updated code causes an increase in the forces acting on the bridge superstructure and foundations in both static and seismic points of view.

(3) In order to choose the recommended subtype of FIAB for retrofitting, the difficulties of the retrofit on different bridge components in real case should be considered.

(4) The influence of different abutment heights on the performance of girders, abutment stems and piles beneath abutments is noticeable or remarkable; however, different pier heights can only affect the performance of piers.

REFERENCES

Burke, M. P., (2009), "Integral and Semi-Integral Bridges," Oxford, UK, Wiley-Blackwell.

Feldmann, M., et al., (2010), Economic and Durable Design of Composite Bridges with Integral Abutments, European Commission, Publications Office of the European Union: Luxembourg. ISBN: Luxembourg: Publications Office of the European Union, 2010.

Maruri, R.F. and S.H. Petro, (2005). *Integral Abutments and Jointless Bridges (IAJB) 2004 Survey Summary*, *in Proceedings of the 2005 FHWA Conference: Integral abutment and jointless bridges*, Baltimore Maryland, United States: Constructed Facilities Center, College of Engineering and Mineral Resources, West Virginia University, 2005.

Xue, J., Briseghella, B., Chen, B., Zordan, T., Siviero, E., Oddone, S. and Mattia, F., (2012). "Retrofitting of simply supported bridges using integral abutment bridge concept," *Twin conference of 5th New Dimensions in Bridges, Flyovers, Overpasses & Elevated Structures* and *13th International Conference on Inspection, Appraisal, Repairs and Maintenance of Structures.* Wuyishan, China.

Xue, J.Q., (2013), "Retrofit of Existing Bridges with Concept of Integral Abutment Bridge-Static and Dynamic Parametric Analyses," University of Trento: Italy, 2013.

Zordan, T., Briseghella, B. and Lan, C., (2011a). "Analytical Formulation for Limit Length of Integral Abutment Bridges." *Structural Engineering International*, Vol. 21, pp. 304-310.

Zordan, T., Briseghella, B. and Lan, C., (2011b), "Parametric and pushover analyses on integral abutment bridge," *Engineering Structures*, Vol. 33, pp. 502-515.