S-Curved Bridges with Extra-large Numbers of Continuous Spans
— Kaneda Viaduct, Metropolitan Inter-City Expressway —

超多径間連続 S 字曲線桁橋
— 首都圏中央連絡自動車道金田高架橋 —

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Synopsis
The Kaneda Viaduct was constructed as a part of Metropolitan Inter-City Expressway in Atsugi City, Kanagawa Prefecture in Japan. The viaduct comprises a couple of S-curved bridges with extra-large numbers of continuous spans carrying dual lanes.
The southbound bridge (hereinafter referred to as “SB”) is a 1,019m long 33-span continuous double-T girder bridge. The northbound bridge (hereinafter referred to as “NB”) is a 1,042m long 34-span continuous double-T girder bridge. The NB has the largest number of continuous spans in Japan.
The seismic design was conducted taking into account the S-curved road alignment and dynamic behaviour of the bridge with seismic isolation bearings.
Super-high-damping rubber bearings are adopted to all the piers for seismic isolation and damping. Their shear deformations were adjusted after structural completions by so-called post-sliding operations to minimise the bearing sizes.

Structural Data
Southbound Bridge (SB)
Structure: 33-span continuous double-T girder bridge
Bridge Length: 1,019.0m
Span: 21.0m + 5@29.0m + 3@36.0m + 3@34.0m + 7@30.3m + 4@31.4m + 9@31.3m + 21.6m
Width: 10.510 – 13.410m

Northbound Bridge (NB)
Structure: 34-span continuous double-T girder bridge
Bridge Length: 1,041.7m
Span: 19.0m + 7@31.0m + 34.0m + 4@32.0m + 11@31.4m + 9@30.6m + 20.9m

Fig.1 Kaneda Viaduct

Width: 10.510 – 14.410m
Owner: Central Nippon Expressway Company Limited
Preliminary Design: Ryoichi SHIOTA (Japan Bridge & Structure Institute, Inc.)
Detailed Design: Hiroshi AKIYAMA (The Zenitaka Corporation)
Contractor: The Zenitaka Corporation (Superstructure)
Construction Period: Apr. 2009 – Mar. 2013 (Superstructure)
Location: Kanagawa Prefecture, Japan

1. Introduction
The Kaneda Viaduct was constructed as a part of the Metropolitan Inter-City Expressway in Atsugi City, Kanagawa Prefecture located about 50km south-west of Tokyo (**Figs.1** and **2**). The Metropolitan Inter-City Expressway is *ca.* 300km long outer ring road of Tokyo Metropolitan area that is located 40–60km from the

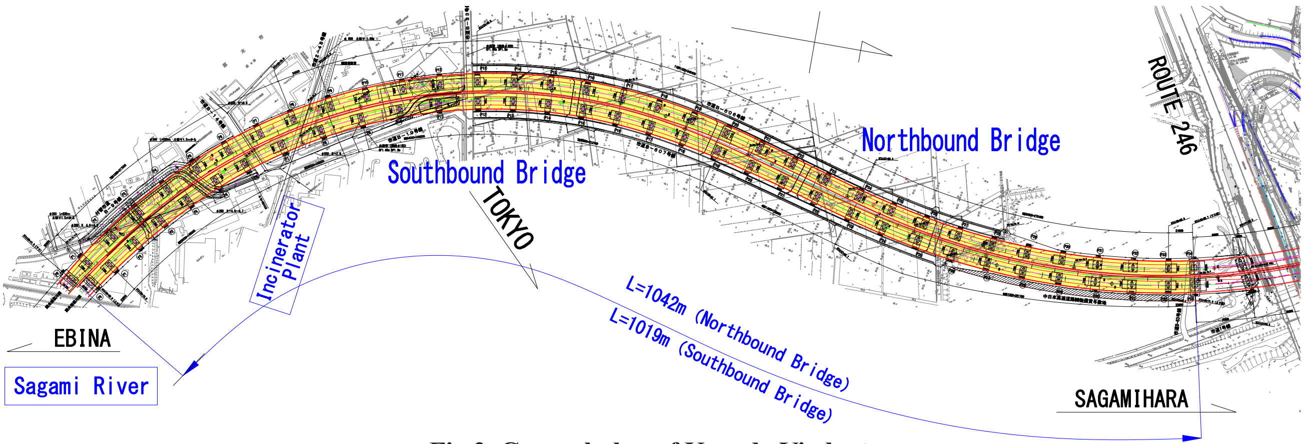

Fig.2 General plan of Kaneda Viaduct

heart of Tokyo.

The Kaneda Viaduct comprises a pair of S-shaped bridges with extra-large numbers of continuous spans.

The minimum radius of curvature in plan of the SB is 450.36m, whereas that of the NB is 465.75m. The bridges were designed with minimum number of expansion joints to obtain the most comfortable serviceability for drivers and maintainability; a continuous structural system was employed that had over 1 km long extra-large number of continuous spans.

The S-curved road alignment was determined taking into account the existing public incinerator plant, privately owned factories and connectivity of adjacent bridges, *i.e.,* a river crossing (left side in **Fig.2**) and a highway overpass (right side in **Fig.2**).

The span layouts were planned such that the cross angle of each span did not exceed 5° to control the influence of torsion due to the curved road alignment.

The special features of the bridges are as follows:

- extra-large numbers of continuous spans;
- seismic design taking into account the S-curved road alignment and dynamic behaviour with seismic isolation through super-high-damping rubber bearings; and
- post-sliding operation of rubber bearings.

2. Design

(1) Substructure Design

Because the bridges are located on the west bank of the Sagami River where subsurface soils are mainly alluvium, pile foundation with 1.2m diameter piles was selected.

Hybrid ribbed steel pipe piles with soil cement were employed for major part of the inner spans (24 SB piers, 25 NB piers) where the ground consist of reclaimed soil with small deformation modulus, so as to accommodate the horizontal displacement of the pile heads.

Conventional cast-in-situ bored pile foundations were chosen for both ends of each bridge where the deformation modulus of the ground was relatively large.

Interlocking piers with circular hoop reinforcement were selected for their excellent ductility.

(2) Superstructure Design

The superstructures comprise extra-large numbers of continuous span prestressed concrete double-T girders (**Fig.3**). The girders were post-tensioned longitudinally with SWPR19L 1S28.6 (JIS G 3536) pre-grouted mono-strands (tensile strength = 949 kN [1782 MPa]).

Pre-grouted mono-strand was employed for highly reliable corrosion protection performance. This is a type of prestressing steel with factory applied corrosion protection. Slow-setting epoxy resin that sets with water in the concrete is filled between the bare strand and high-density polyethylene sheath.

The longitudinal tendons were stressed and anchored for every two spans except the closure spans of both bridges and the first span of the NB (**Fig.6**).

They were not connected with coupling devices at the construction joints, but instead were individually anchored at the construction joints or anchor blisters at the inner side of webs to eliminate the risk of incomplete coupling. The deck slabs were also transversally post-tensioned with pre-grouted monostrands.

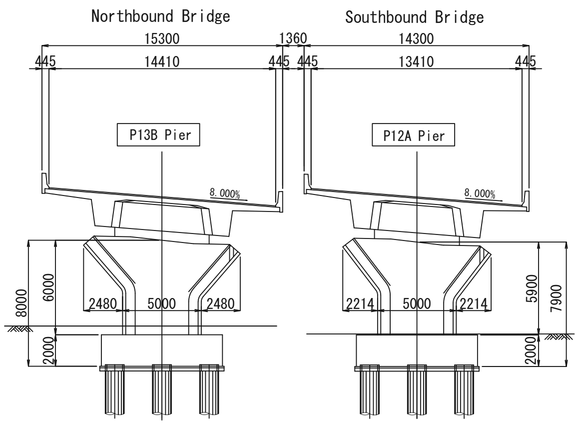

Fig.3 Cross sections (Units: mm)

(3) Seismic Design

1) Outline of Seismic Design

Because seismic load dominates the dimensioning of piers and foundations in a high-risk seismic zone as Japan, seismic isolation bearings made of super-highdamping rubber were employed for all the piers

because of their low pier heights that range from 4.4m to 10.3m, and non-liquefiable soil conditions. Those bearings enable seismic isolation and seismic energy dissipation.
The seismic design was carried out with three-dimensional dynamic analysis for level-1 and level-2 earthquake motions considering their S-curved alignments and the behaviour of extra-large numbers of continuous spans with isolation bearings.
Here, level-1 earthquake motions are defined as middle class earthquake motions having a high possibility of occurrence in the lifetime of the structure.
Level-2 earthquake motions are defined as the maximum class strong earthquake motions that could occur in the present or future including ocean interplate earthquake motions (hereinafter referred to as “type-I earthquake motions”) and inland epicentral earthquake motions (hereinafter referred to as “type-II earthquake motions”).
The results of eigenvalue analysis revealed that there were no apparent longitudinal and lateral directions for the bridge vibrations. Therefore, the dynamic analyses were conducted for every 30° seismic input direction in plan (**Fig.4**).

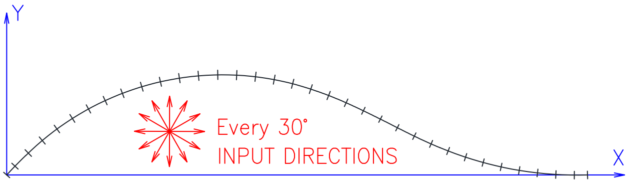

Fig.4 Input directions in plan

2) Seismic Design for Level-1 Earthquake Motions
Linear response spectrum analysis with the complete quadratic combination method was conducted for level-1 earthquake motions considering the dynamic behaviour at the curvature and isolation bearings. The maximum displacement of the superstructure in level-1 earthquake motions is *ca.* 75mm. The maximum displacement of each bearing appears when the cross angle between input direction and tangential direction of bridge axis at each position becomes minimal.
All the members including steel finger expansion joints are designed to behave as elastic members in level-1 earthquake to assure the sound serviceability afterward.

3) Seismic Design for Level-2 Earthquake Motions
Seismic design for level-2 earthquake motions was performed using nonlinear time-history response analysis. Two types of earthquake motions were considered by using three typical acceleration waves for each type. The peak ground acceleration of type-I earthquake motions is 384.9 Gal, and that of type-II earthquake motions is 736.3 Gal. Type-II earthquake motion is dominant events for these bridges. The maximum displacement of the superstructure in type-II earthquake motions is *ca.* 500mm, whereas it is *ca.* 350mm in type-I earthquake motions.

3. Bearings
Super-high-damping rubber bearings were employed to isolate earthquake motions and absorb seismic energy.
These bearings have higher damping performance than conventional isolation bearing by *ca.* 20%.
The seismic isolation provided an economical way to ensure safety against earthquake while having compact piers and foundations.
The horizontal stiffness of isolation bearings (*e.g.* that of those at the end piers) are *ca.* 80% of those of conventional non-isolation rubber bearings of the same size. Accordingly, they ease the indeterminate forces of thermal effects, prestressing force, creep and shrinkage. This ensures the economic feasibility of the extramultiple span continuous long bridge.
Because these bridges are over 1km long and extramultiple span structures, displacement due to prestressing force, creep, shrinkage and thermal effects are major actions for dimensioning the end-side bearings. Post-sliding operation was carried out to minimise the bearing sizes by offsetting the initial shear deformations of rubber bearings. Post-sliding operation also releases the axial tensile force in the superstructure originating from indeterminate force for prestressing, creep and shrinkage.
In addition, post-sliding operation decreases the bending moment and shear force for piers. It is particularly effective for long multiple span continuous bridges, because the axial tensile force in the superstructure grows with the bridge length and the number of continuous spans. Without the post-sliding operation, larger size bearings are required.
Post-sliding operations of the bearings were carried out along the strong axis of the pier cross sections using a maximum of six jacks with a 500kN/nos. capacity for each bearing (**Fig.5**). The maximum sliding length was 145mm. Post-sliding operation was applied to 20 piers each bridge. The differences between measured and expected displacements of both end bearings of both bridges were *ca.* 10mm at the time of handover inspection, which was 5.5 months for the SB and 4.0 months for the NB after the structural completions.

Fig.5 Post-sliding operation

4. Construction

(1) Erection of Double-T Girder

The construction sequence is illustrated in **Fig.6**. The bridge was erected by the conventional cast-in-situ method with a shoring system for low pier height condition. Concurrent erection enabled rapid construction; six erection teams (*i.e.,* three teams for each bridge) performed the erection at the peak of the construction.

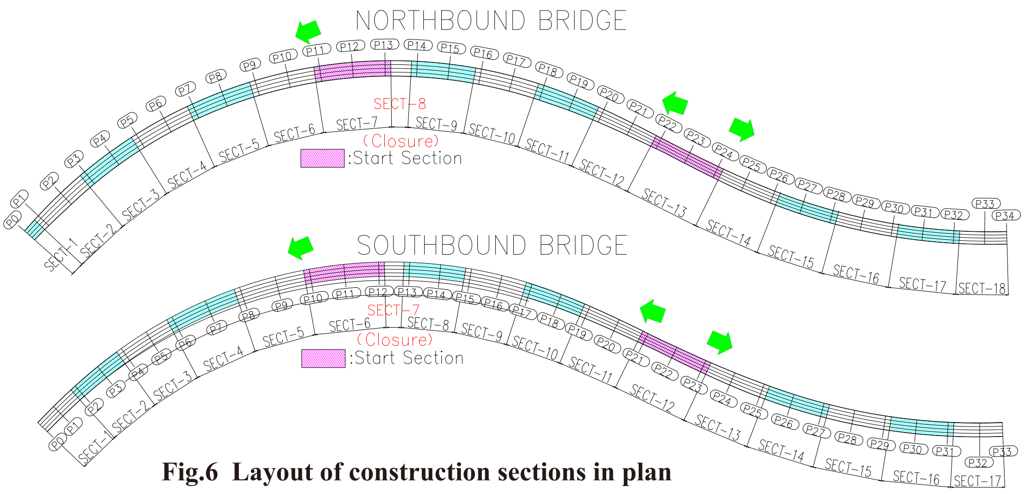

Fig.6 Layout of construction sections in plan

The NB was subdivided into 18 sections, whereas the SB was subdivided into 17 sections. The erection of each bridge was commenced from two locations (*e.g.,* Sect-7 and Sect-13 of the NB) and continued forward in three directions, one after another.

The closure sections (*i.e.,* Sect-8 of the NB and Sect-7 of the SB) were further longitudinally subdivided into two sections for concreting. The final casting of the closure sections (L = 1.0m) was carried out with longitudinal temporary struts and ties to prevent cracking by thermal displacement.

The struts comprised H-steels against compression, whereas the ties comprise φ32mm prestressing bars against tension to fix both adjacent sections to the final closure sections.

5. Conclusion

The extra-multiple span continuous S-curved bridges were constructed economically by using post-sliding operation for the bearings. The isolation design with super high-damping rubber bearings also improved the economical aspect. The seismic design considering the S-curved alignment through dynamic analysis ensured adequate seismic performance.

The bridges enable comfortable serviceability for drivers and maintainability for the minimum number of expansion joints, accomplished by the extra continuity of the spans.

Fig.7 Completed bridges

The benefits of seismic isolation bearings to long multiple span continuous bridges can be attributed to their soft horizontal constraint in service state and seismic performance; seismic isolation system lends itself to long multiple span continuous bridges, particularly in the regions with high seismic risk.

References

[1] Akiyama, H., Tanaka, I. et al.: *Extra multiple span Continuous S-Curved Bridges—Kaneda Viaduct, Metropolitan Inter-City Expressway*, Japan, Structural Engineering International, Vol.24, No.3, IABSE, Zurich, pp. 381–386, Aug. 2014. doi:10.2749/101686614X13844300210399

概　要

金田高架橋は首都圏中央連絡自動車道の一部をなすPRC33径間連続桁橋（上り線）およびPRC34径間連続桁橋（下り線）である。下り線は，わが国における最多連続径間数を有する橋梁である。

橋長が1kmを超える超多径間連続桁橋であることに加え，従来，ほぼ直線橋であった長経径間連続桁橋とは異なり，最少曲率半径450.360mを有し，S字曲線を描く曲線橋に免震構造を採用している。耐震設計では，超多径間連続構造かつS字曲線橋である本橋の地震時の動的挙動を正確にシミュレートするためにレベル1地震動に対しては線形応答スペクトル法により解析を行い，レベル2地震動に対しては非線形時刻歴応答解析を用いて，地震入力方向を30°毎に設定して検討を行った。

施工では，ポストスライド工を各橋脚断面の強軸方向に後ひずみ調整を実施したほか，橋長1kmを超える長大橋の閉合部では温度変化による影響が無視できないため，H形鋼とPC鋼棒を用いた仮設の変位拘束工を設けて閉合部での変形を拘束した状態で閉合工を行う等の工夫を行った。