Vibration Study and Seismic Performance Analysis on Combined System of Deck slab and Non - prismatic Girders with Double Corrugated Composite Webs During Real Earthquake

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Abstract - *Corrugated web plates have a lot of benefits as compared with flat web plates to bridge girders like more buckling strength, web stability, better load carrying capacity etc... This paper focuses on Double corrugated web girders which consists of two corrugated steel web plates which are parallelly placed and separated by a small gap or hollow space and with flanges at bottom and top. Here Double Corrugated Composite Web consists of Ultra-Lightweight Cement Composite (ULCC) fill in the hollow space in between the two corrugated steel webs for making the web portion thick and strong. Here vibration study under Modal analysis and seismic performance analysis of combined system of deck slab and Non-prismatic Girders with Double Corrugated Composite Webs (DCCWG) during real earthquake was done using the Finite Element software ANSYS 16.1 WORKBENCH. Seismic performance of the model under the effect of earthquake motion which was applied in both the directions perpendicular and parallel to the bridge axis was investigated by Transient structural analysis with respect to El Centro earthquake Peak Ground Acceleration (PGA) data. The substructure component of the bridge is beyond the scope of this present study. According to the results obtained by Transient Structural Analysis, the peak values of seismic response parameters like base shear, displacement and acceleration with respect to the time for the earthquake applied in X- direction are higher than the value of base shear, displacement and acceleration obtained for Z direction.*

***Key Words*: Double corrugated web, Transient Structural analysis, Non - prismatic Girders, Ultra-Lightweight Cement Composite, seismic response parameters**

1. INTRODUCTION

The effective uses of corrugated steel plates are increasing day by day all over the world for many civil engineering applications such as shear walls, bridge girders, webs of columns and beams of buildings etc… The corrugated web plates were already used for many existing steel and composite bridges constructed in different countries, for example Dole bridge constructed in France. Corrugated plates are widely adopted for the web portion of the girders in field of bridges. The web plates can be provided with steel flanges, composite flanges or prestressed concrete flanges. These webs are more suitable for plate girders. But it can be adopted for box girders too. A lot of studies are carried out on the performance of bridge girders with Single corrugated steel webs. The improvement of the static structural performance of Single corrugated webs by providing concrete encasement or stiffeners were studied in existing researches. No detailed studies are carried out on Double corrugated web girders yet. Double corrugated web girders which consists of two corrugated steel web plates which are parallelly placed and separated by a small gap or hollow space and with flanges at bottom and top. Here Double Corrugated Composite Web consists of Ultra-Lightweight Cement Composite (ULCC) fill in the hollow space in between the two corrugated steel webs for making the web portion thick and strong.

B. Kovesdi, L. Dunai [1], conducted both experimental and numerical investigations on corrugated steel web girders and patch loading resistance and failure modes were analysed for different specimens. Various parameters related to the geometric details of corrugated web portion affecting structural performance of bridge girders was observed in detail in this paper. E. Zevallos et. al [2], conducted study on tapered or Non- prismatic girders with corrugated web through nonlinear finite element analysis. From this paper, the out of plane deformation was found to be very less for corrugated web plates because of their higher out-of-plane stiffness as compared to conventional flat web steel plates. Jun He et.al [3], conducted study on concrete encased composite girder with corrugated steel webs. The concrete encasement provided along with the corrugated web improved overall performance of the girder. Jun-Yan Wang et.al [4], specified the advantages of using the material, Ultra-Lightweight Cement Composite (ULCC) fill for composite structures. This material possesses certain characteristics such as high specific strength with very light weight as compared with the conventional concrete material. Zhi-Yu Wang, Xiaolei Li et.al [5], conducted a comparative study on corrugated web girders with concrete filled rectangular hollow section (RHS) flanges or composite flanges and normal steel flat flanges. The performance of the girder was enhanced by means of providing concrete filled rectangular hollow section (RHS) flanges. The tendency of flange buckling of the girder will be comparatively more at top than bottom. In this present study, the Non-prismatic girder is provided with composite flange (CF) at top and the flat flange (FF) at bottom.

From Literature reviews, it can be found that almost studies are focused on the topics related to buckling behaviour, shear capacity, load carrying capacity, and web stability of Corrugated web girders and no detailed study is conducted to evaluate their seismic performance during any real earthquake situations. Here vibration study under Modal analysis and seismic performance analysis of combined system of deck slab and Non - prismatic Girders with Double Corrugated Composite Webs (DCCWG) during real earthquake was done using the Finite Element software ANSYS 16.1 WORKBENCH. The main objective of this study is to analyse the seismic response of this combined system under a real happened earthquake.

2. INPUT EARTHQUAKE MOTION

The Transient structural analysis was done with respect to real happened earthquake in Southern California, El Centro earthquake Peak Ground Acceleration (PGA) data. Fig 1 shows El Centro earth quake– peak ground acceleration (PGA) data or Acceleration time history graph of El Centro earthquake having PGA of 3420 mm/s^2 occurred at 2.14 sec. The combined system of girders and bridge deck was analysed under the effect of this earthquake motion which was applied in both X and Z directions.

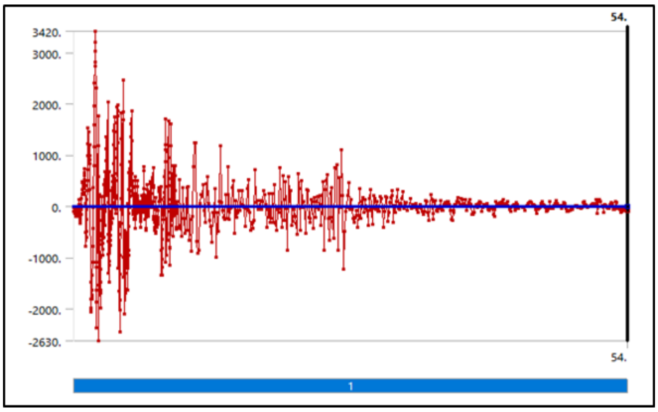

Fig-1: El Centro earth quake: Acceleration -time graph

3. NUMERICAL INVESTIGATION USING ANSYS 16.1

3.1 Numerical Modelling of Non-prismatic Girder

Numerical modelling of the specimen was done on ANSYS 16.1 WORKBENCH. The girder adopted is Non – prismatic Girder with Double Corrugated Composite Web (DCCWG) having Composite flange at top and Flat Flange at bottom. The geometric properties of corrugated web portion are shown in Fig-2.

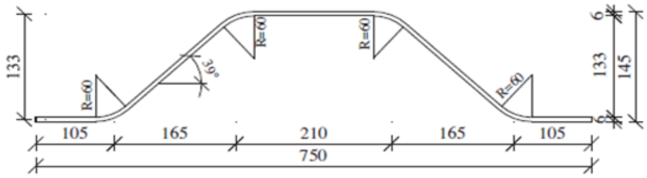

Fig -2: The geometric properties of corrugated web [1]

The geometry of the girder is shown in Fig-3 below. Double corrugated web girders which consists of two corrugated steel web plates which are parallelly placed and separated by a small gap or hollow space and with flanges at bottom and top. Here Double Corrugated Composite Web consists of Ultra-Lightweight Cement Composite (ULCC) fill in the hollow space in between the two corrugated steel webs for making the web portion thick and strong as shown in Fig-4.

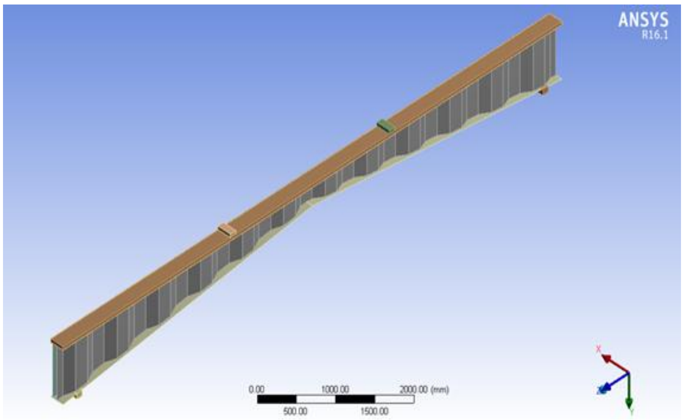

Fig - 3: Non – prismatic Girder with Double Corrugated Composite Web (DCCWG) having CF @ top and FF @ bottom

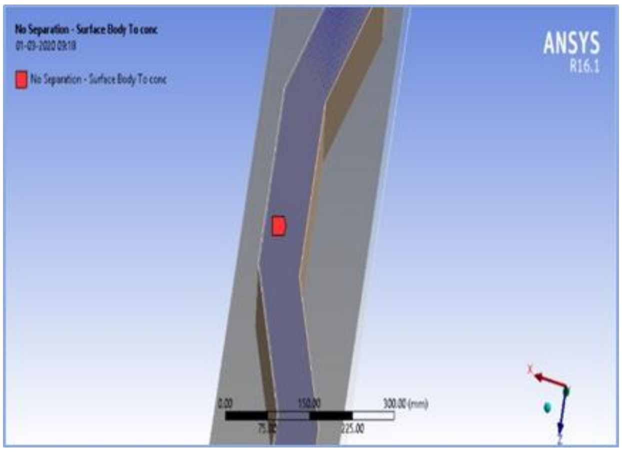

Fig - 4: Double Corrugated Composite Web

Composite flange is ULCC filled Hollow Section flange. The girder was modelled using SHELL 181 elements. The length of girder is 9000 mm. Thickness of flat flange is adopted as 20 mm and for corrugated web is 6 mm. Width of flange is taken as 225 mm. The thickness of Composite Flange (CF) is 50mm.The maximum height of corrugated web adopted was

800 mm on one side and minimum height of 200 mm on other side of linearly tapered girder with a tapered ratio of 4. The girder is simply supported at both ends. The material properties of the steel and ULCC are assigned and which are mentioned in Table-1.

Table -1: Material properties of Non - prismatic Girders

Properties	Values
Modulus of Elasticity of Steel	2 x 10^5 N/mm^2
Poisson's Ratio of Steel	0.3
Yield strength of Steel	379 MPa
Density of Steel	7860 kg/m^3
Modulus of elasticity of ULCC	10.62 GPa
Poisson's Ratio of ULCC	0.15
Density of ULCC	1250 kg/m^3

3.2 Numerical Modelling of Combined system of Deck and Non-prismatic Girder

Numerical model developed for the study is the combined system of two girders and bridge deck. The ULCC composite deck slab was modelled with SOLID 65 element. The basic dimensions of the deck slabs are- thickness of 250mm, length of 9000 mm and width of 2250 mm. Fig- 5 shows the geometry of the numerical model. The girders are simply supported at both ends.

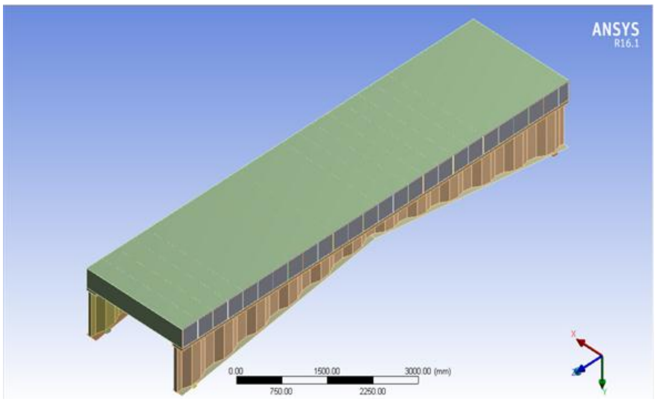

Fig- 5: Geometry of the numerical model

Modal analysis uses over all mass of structure only to find out the time period and frequency of vibrations. In Transient structural analysis, the combined system of girders and bridge deck was analysed under the effect of earthquake motion which was applied in both the direction perpendicular and parallel to bridge axis. Boundary conditions for EQ-X and EQ-Z directions are shown in Fig-6 and Fig-7.

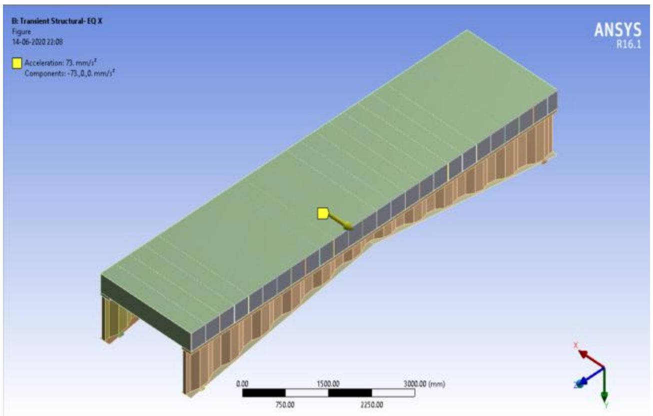

Fig-6 : Boundary condition for EQ-X direction

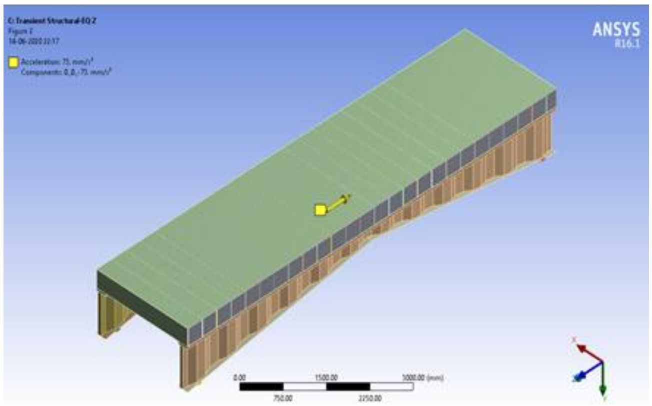

Fig- 7: Boundary condition for EQ-Z direction

4. RESULTS AND DISCUSSION

4.1 Results of Modal Analysis

After Modal analysis, Fundamental frequency (f) and Time period (T) of vibration of the numerical model were obtained both in both Transverse and Longitudinal direction. Fig-8 shows Fundamental frequency (f) value and total deformation obtained at transverse direction and Fig-9 shows Fundamental frequency (f) value and total deformation obtained at longitudinal direction by modal analysis. At transverse direction, Fundamental frequency (f) was obtained as 29.828 Hz and at longitudinal direction 68.305 Hz was found. The results obtained from Modal analysis are shown in Table 2.

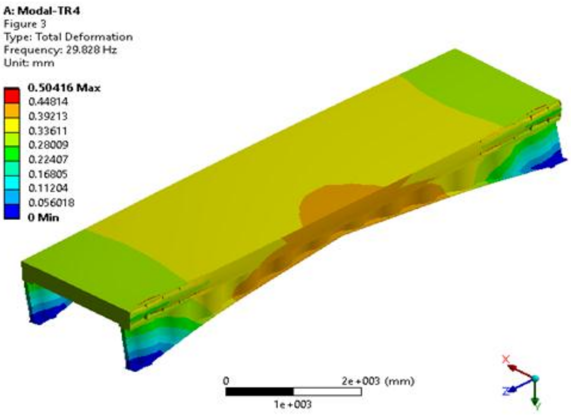

Fig -8: Fundamental frequency and Total deformation at Transverse direction

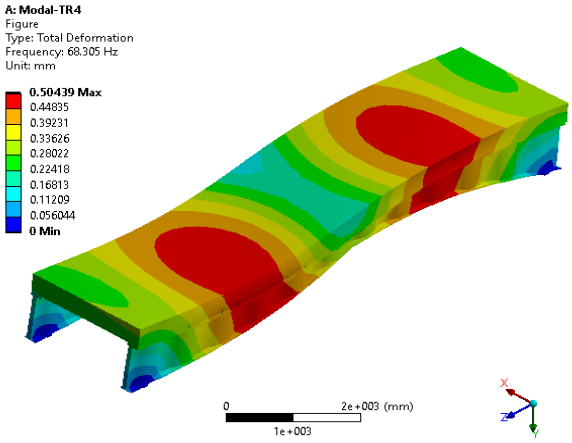

Fig – 9: Fundamental frequency and Total deformation at Longitudinal direction

Table -2: Fundamental frequency (f) and Time period(T)

Direction	Fundamental frequency (f) of vibration	Time period (T) of vibration
At Transverse direction	29.828 Hz	0.0335 s
At Longitudinal direction	68.305 Hz	0.0146 s

From the vibration study under modal analysis, it was observed that the structure possesses large value of fundamental frequency of vibration at longitudinal direction comparatively at transverse direction. While comparing total deformation in both directions, the deformation was very less under vibrations. The Fig-8 and Fig-9 show how the system will respond during vibration and it is most important one in the field of Bridge Engineering, that should be considered into account during structural design.

4.2. Results of Transient Structural Analysis or Time - History analysis

Chart 1, Chart 2 and Chart 3 show the seismic response parameters in terms of base shear, displacement and acceleration with respect to time for the earthquake applied in X direction of numerical model.

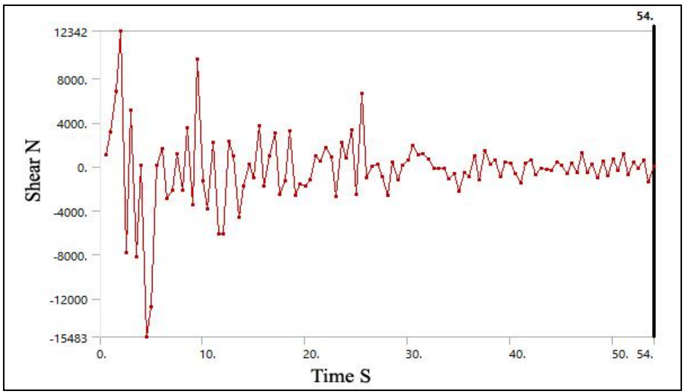

Chart – 1: Base shear v/s time for EQ- X direction

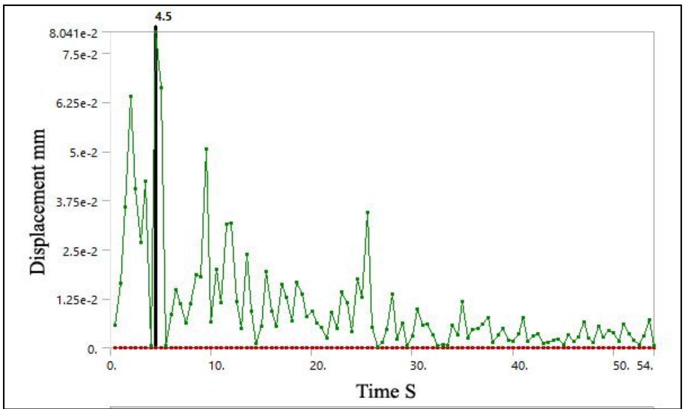

Chart - 2: Displacement v/s time - for EQ- X direction

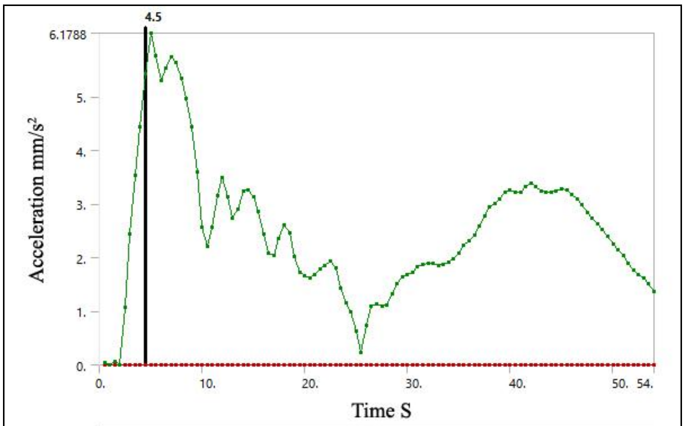

Chart – 3: Acceleration v/s time for EQ- X direction

Chart 4, Chart 5 and Chart 6 show the seismic response parameters of the model in terms of base shear, displacement and acceleration for the earthquake applied in Z direction. The peak values of seismic response parameters at both directions are tabulated below in Table 3.

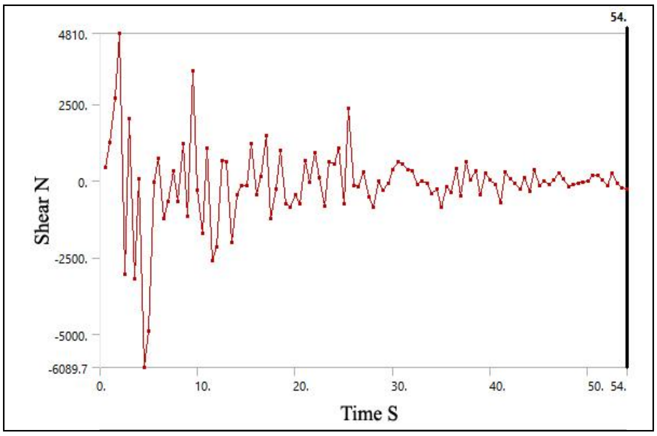

Chart -4: Base shear v/s time for EQ-Z direction

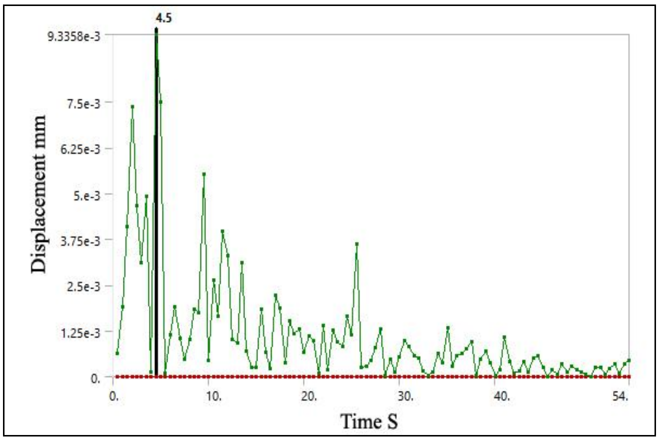

Chart -5: Displacement v/s time for EQ – Z direction

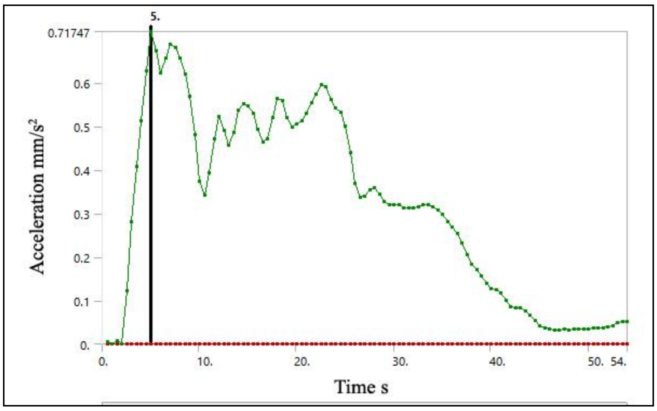

Chart -6: Acceleration v/s time for EQ – Z direction

Table – 3: Seismic response parameters

Direction	Acceleration mm/s²	Displacement mm	Base shear N
EQ - X	6.178	0.08041 mm	12342 N
EQ - Z	0.7174	0.0093 mm	4810 N

From this study value of seismic response parameters acceleration, base shear and displacement have been determined. According to the results obtained by Transient Structural Analysis or Time - History analysis, the peak value of base shear, displacement and acceleration with respect to the time in the EQ - X direction is higher than the value of base shear, displacement and acceleration with respect to the time in the EQ - Z direction. From the Charts 1 and 4, it was observed that in both earthquake directions, model possesses positive and negative base shear. In X- direction maximum value of base shear force 12342 N occurs for a time interval of 0 to 10 sec and after 30 sec the model has almost a steady value of Base shear. For Z- direction maximum value of base shear force 4810 N occurs for a time interval of 0 to 10 sec and here also beyond 30 sec the model has almost a steady value of Base shear. Results show that very low deformation was observed for the model under El-Centro earth quake and other parameters such as base shear also satisfactory in terms of recorded data.

5. CONCLUSIONS

In this paper vibration study under Modal analysis and seismic performance analysis of combined system of deck slab and Non - prismatic Girders with Double Corrugated Composite Webs (DCCWG) during real earthquake was done using the Finite element software ANSYS 16.1 WORKBENCH. The following are the conclusions derived from this paper,

- From the vibration study under modal analysis, it was observed that the structure possesses large value of fundamental frequency of vibration at longitudinal direction comparatively at transverse direction. While analyzing the total deformation values, the displacement occurred during the vibration in both directions is very less.

- Peak value of the seismic response parameters such as base shear, displacement and acceleration with respect to the time for the earthquake applied in X direction is higher than the base shear, displacement and acceleration obtained with respect to the time for the earthquake applied in Z direction.

- Results show that very low deformation was observed for the model under El- Centro earth quake and other parameters such as base shear also satisfactory in terms of recorded data. So that the structure can be anticipated to exhibit very good performance.

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