International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2763
Issue 06, Volume 3 (June 2016) www.ijirae.com

GIRDER DESIGN OF A BALANCED CANTILEVER BRIDGE WITH ANALYSIS USING MIDAS CIVIL

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Abstract— Balanced cantilever bridges are used for special requirements like 1) Construction over traffic 2) Short lead time compared to steel 3) Use local labour and materials. If continuous spans are used, the governing bending moment can minimised and hence the individual span length can increase. But unyielding supports are required for continuous construction. Hence for the medium span in the range of about 35 to 60 m, a combination of supported span, cantilever and suspended span can be adopted and bridge with this type of superstructure is known as balanced cantilever bridge. This chapter include the analysis and design of a 50m span prestressed balanced cantilever bridge which comprises of 6 numbers of Pre-Cast Post Tensioned-I Girder 38m long Simply Supported at one end and connected through a Cast-in-Situ Stitch Concrete to a Continuous Balanced Cantilever Box Girder (2x11m). The bridge structure has been modelled by Finite element Technique using MIDAS Civil and analysis has been performed to get various output such as primary and secondary bending moment, shear forces and torsion quantities at various locations of the bridge. The design of super structure is performed as per IRC standards.

Keywords— Balanced cantilever bridge, Prestressed, I girder, Box girder, Primary and secondary moments and MIDAS Civil

I. INTRODUCTION

Balanced Cantilever Bridge is so named due to its method of construction. It is one of the most efficient methods of building bridges without the need of false work. This method has great advantages over other forms of construction in urban areas where temporary shoring would disrupt traffic and services below, in deep gorges, and over waterways where false-work would not only be expensive but also a hazard. Construction commences from the permanent piers and proceeds in a “balanced” manner to mid span. Before starts design dimensions are assumed based on experience. The design involves calculation of the section properties, primary and secondary moments, magnitude and location of the prestressing force, profile of the tendons, losses due to prestressing, shear stresses at different sections.

A. MIDAS CIVIL

New standard for the design of bridges and civil structures. It features a distinctively user friendly interface and optimal design solution functions that can account for construction stages and time dependent properties. Its highly developed modelling and analysis functions enable engineers to overcome common challenges and inefficiencies of finite element analysis. With midas Civil, you will be able to create high quality designs with unprecedented levels of efficiency and accuracy. MIDAS/Civil (Bridge) analyses and designs any bridge structures in 3-D environments, accounting for construction stages and time-dependent materials. It covers curved (girder), composite, segmental post-tensioning, suspension, cable-stayed, skewed slab, frame, and culvert bridges. It generates comprehensive traffic loads to AASHTO standard and LRFD, CSA-S6-00, IRC and BD37 through influence lines and surfaces. Analysis of post-tensioning segmental bridges reflects creep, shrinkage, and all tension losses. Forward-stage large displacement analysis for cable-stay bridges can be handled concurrently with post-tensioning segmental spans in comprehensive construction stages. Bridge-rating capabilities are also included.

B. FINITE ELEMENT METHOD AND ELEMENT FORMULATION

The finite element method (FEM) is a general tool for solving differential equations suitable for structural engineering applications. FEM is capable of handling large structural mechanics problems by discretising the problem into a finite number of elements, which in turn is governed by equations. Since the element equations govern the model and the results, it is important that designers have a fair understanding of the underlying assumptions of these elements. The elements used in FEM can roughly be categorized in three different categories; continuum elements, structural elements and special purpose elements. Continuum elements describe the structure as a continuum, and give the stress-state in the structure. This includes 3D solid elements and 2D plane stress/strain elements. Since these elements work with the stresses of the structure they describe the real behaviour of the structure and lack some of the limitations of the structural elements. However, the output from an analysis based on such elements is often massive and difficult to apply on reinforced concrete design since the design of such structures are more easily done based on sectional forces. In order to design concrete structures according to current praxis on basis of 3D-volume elements, integration of cross-sections has to be performed in order to get the sectional reactions.

Structural elements are based on the equations of for example beam and plate theory. This makes structural elements suitable for design since they provide sectional forces directly for each cross-section. Structural elements also allows for a simpler and more intuitive modelling process.

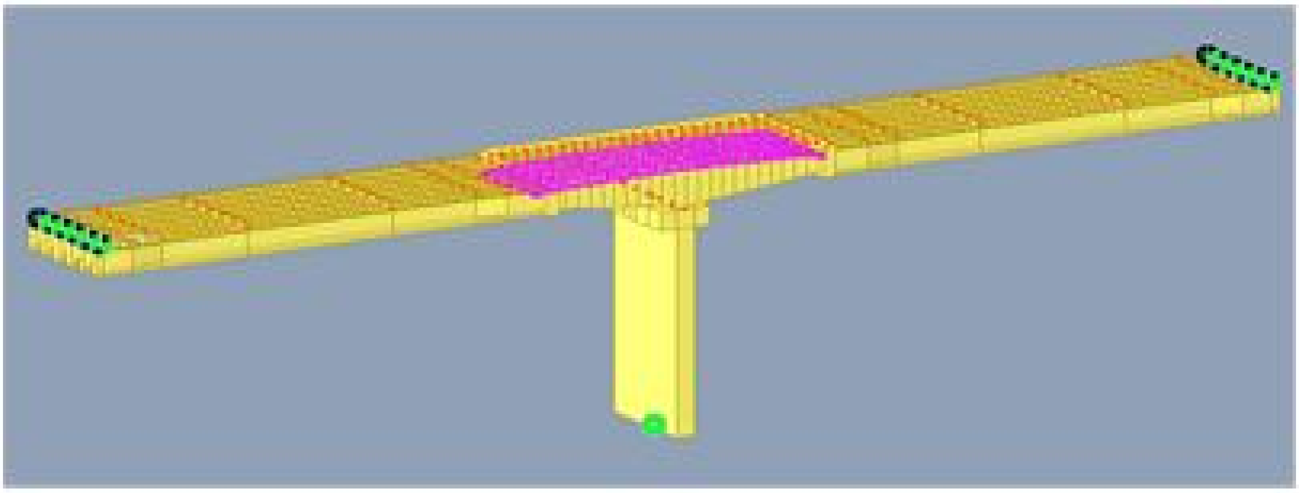

Fig. 1 Midas model of the bridge

II. STRUCTURAL DATA

Span	: 50m
Width of Deck Structure	: 12m
Width of Carriageway	: 7.50m
No of Lanes	: 2
Type of Super Structure	: Post Tensioned I-Girders & Cast-in-situ Box girder. I girder and the cast- in-situ box girder is connected with cast-in- situ stitch concrete.
Footpath Details	: 1.75m wide footpath of precast RCC slab resting on Crash barrier on one side and on the other end on cast- in-situ RCC kerb.
Type of Crash Barrier	: New Jersey RCC cast-in-situ
Longitudinal Slope	: 0.3%
Transverse Slope	: 2.5%
Type of Bearing	: POT/PTFE guided bearings (465 X 350 X 100) at simply supported ends.
Concrete Grade for Superstructure	: M45
Grade of Steel	: Fe-500 Grade TMT bars
Grade of Steel for Prestressing Cables	: High tensile steel of Uncoated Stress relieved strands (12 T 13 &19 T 13)
Expansion Joint	: Strip seal joint
Drainage of Deck	: Through PVC drainage pipes taken out from drainage spouts at either end of deck slab suitably spaced.

III. LOADING CONSIDERED AS PER IRC SPECIFICATIONS

1 Dead load of structural elements such as deck slab, I Girders, Box Girder, Diaphragms
2 Superimposed dead loads due to Footpath dead load, Footpath live load, Wearing coat and crash barrier etc.
3 Moving loads due to IRC-Class-A vehicle ,IRC-70R vehicle loading and their critical combinations
4 Impact of vehicular live load
5 Longitudinal forces caused by tractive effort of vehicles
6 Forces due to erection of girders
7 Forces due to temperature rise / fall
8 Forces due to shrinkage and creep of concrete
9 Forces due to braking of vehicle
10 Forces due to wind effect on deck system
11 Forces due to seismic effect
12 Forces due to differential settlement of support
13 Force due to hyperstatic effect of prestress

IV. PRINCIPLE AND MODELLING OF PRESTRESSING

Any method, which satisfies the requirements of equilibrium and compatibility and utilizes stress-strain relationships for the proposed material, can be used in the analysis. As it is commonly known, the prestressing force used in the stress computation does not remain constant with time. The collective loss of prestress is the summation of all individual losses, which may be examined individually or considered for a lump sum loss. Four most critical conditions in the structural modelling of tendons:

- *Immediate loss of stress in tendon:* Friction between the strand and its sheathing or duct causes two effects :(1) Curvature friction, and (2) Wobble friction. The retraction of the tendon results in an additional stress loss over a short length of the tendon at the stressing end. The combined loss is commonly referred to as the friction and seating loss.
- *Elastic shortening:* The elastic shortening of the concrete due to the increase in compressive stress causes a loss of prestressing force in tendons.
- *Long-term losses:* Several factors cause long-term losses: (1) Relaxation of the prestressing steel, (2) Shrinkage in concrete, and (3) Creep in concrete. In grouted (bonded) post tensioning systems, creep strain in the concrete adjacent to the tendon causes a decrease in tendon stress. For unbonded tendons, the decrease in stress along the tendons due to creep of the concrete is generally a function of the overall (average) precompression of the concrete member.
- *Change in stress due to bending* of the member under applied loading: For a rigorous evaluation of the affected member, change in stress must be taken into count, particularly when large deflections are anticipated.

V. ANALYSIS AND DESIGN OF POST TENSIONED BOX GIRDER AND I GIRDER

- Plan and cross section drawing of the girders are as shown below. Stresses have been checked at the following sections.

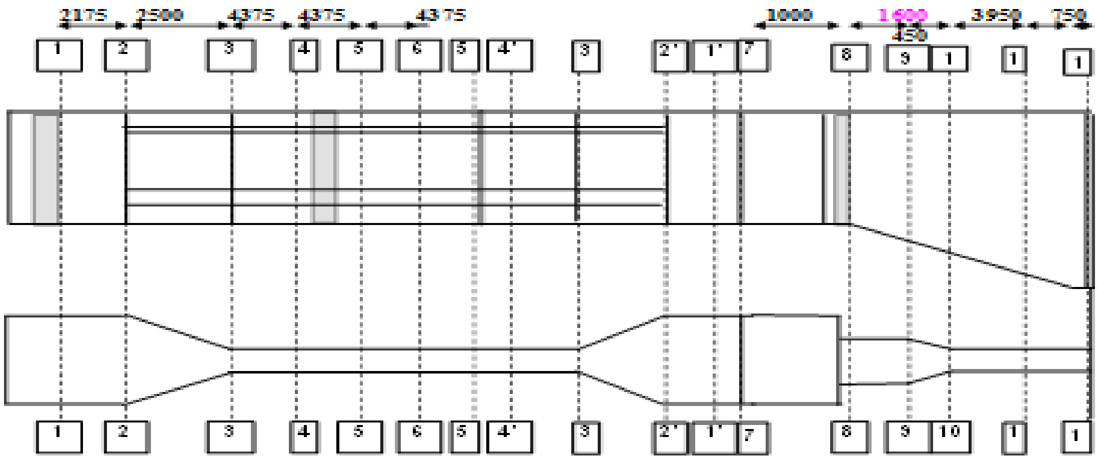

Fig. 2 Plan and cross section

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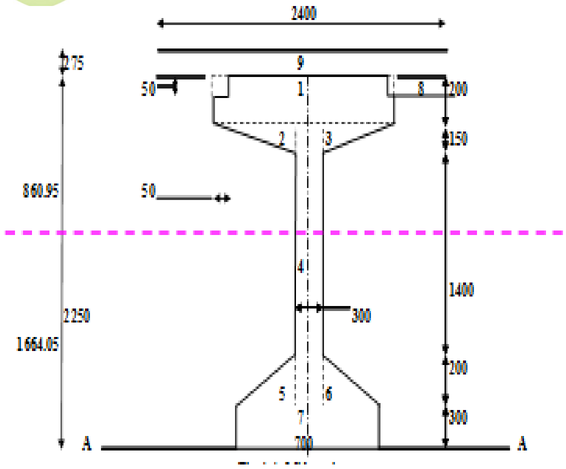

Fig. 3 Cross section of I girder

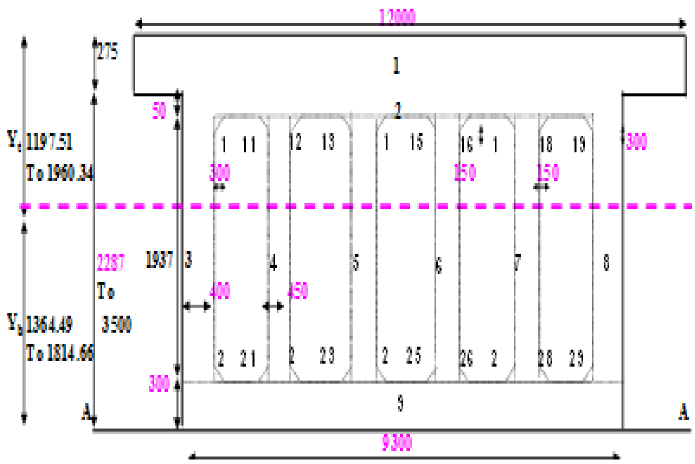

Fig. 4 Cross section of box girder

- Bending moments and shear forces at each sections due to all loading are find out from midas output and ultimate moments at each sections are find out according to the formula given below
  Ultimate moment = [1.5 x G] + [2 x SG] + [2.5 x Q]
  Where
  G = Permanent load
  SG = Superimposed load
  Q = Live load

TABLE I
BENDING MOMENTS AT DIFFERENT SECTIONS

BM DUE TO	SECTIONS KNM									
	1-1	2-2	3-3	5-5	6-6	8-8	9-9	10-10	11-11	12-12
GIRDER	456.6	1520	2508	4549	4837	-62.92	-214.3	3486.2	-9714	-18980
ERECTION LOAD	474.3	1603.9	2668.15	4932.5	5236.65	-1031.1	-2574.1	-14206	-24646	-34914
PRE CAST SLAB	3.186	27.68	53.31	115	120.7	-	-	-	-	-
DIAPHRAGM	6.6	62	126	309	311	-	-	-	-	-
CONSTRUCTION LL	66.42	566.6	1090	2353	2467	-12.479	-32.76	-780.2	-2339.8	-4689.2
DECK SLAB	51.52	587.41	1106.7	2148.4	2342.6	-	-	-	-	-
CRASH BARRIER	4.191	170.5	306.7	425.1	497.8	-1276.9	-2012.9	-2739	-4638.6	-6830
FOOTPATH DL	3.66	89.79	159.5	215	255	-988.9	-1095.4	-1461.6	-2474.8	-3644.2
WEARING COAT	5.948	41.89	83.43	198.2	186.4	-924.8	-1016	-1354	-2290.4	-3251
FOOTPATH LL	5.127	125.7	223.3	301	357	-1395.6	-1533.8	-2046.2	-3464.8	-5102
GIRDER +PLANK+ DIAPHRAGM+ DECK	151.8	1681.0	3110.0	5819.0	5987.38	-25475	-28531	-40132	-71661	-108811
VEHICLE LL	35.58	160.8	320.3	767.007	799.307	-5133.6	-5340.5	-5501.8	-8472.4	-11291
HYPERSTATIC	-6.453	-51.77	-98.49	-278.2	-365.6	6209.3	6842.1	8974.5	4225.9	5947.1
TEMP. RISE	10.28	100.5	202.9	565.7	746.9	9427	9536	9932	10916	11900
TEMP. FALL	-4.342	-47	-96.27	-268.2	-354.9	-4474.8	-4517.1	-4722.4	-5182.7	-5649.3
SETTLEMENT CENTRE	1.886	18.82	38.07	106.2	140.5	1762.7	1783.4	1857.6	2041.8	2225.8
SETTLEMENT LEFT	-1	-10.24	-20.77	-57.97	-76.72	-962	-973.2	-1014	-1114.4	-1214.8
SETTLEMENT RIGHT	-0.877	-8.575	-17.33	-48.27	-63.81	-800.6	-809.8	-843.8	-933.4	-1011
SHRINKAGE	-0.544	-6.565	-13.64	-37.87	-49.85	1448.8	1441.6	1414	1347.8	1281.4
CREEP	-0.102	-1.226	-2.547	-7.074	-9.311	270.59	269.24	264.2	251.76	239.34
ULTIMATE MOMENT	319.1	3439.47	6345.86	1162.07	12253.3	-54548	-61099	-80145	-138227	-204447

- For I girder 5 numbers of 19T13 cables are used and one 12T13 cable as dummy cable. The cable ordinates ,cable profile, losses due to friction and slip are calculated and forces in each cable after this losses are tabulated. Here prestressing has to carried out in two different stage , In first stage cable 1 & 2 are stressing after casting of girder. And second stage is carried out after casting the duck slab, i.e. cable 3, 4 & 5.

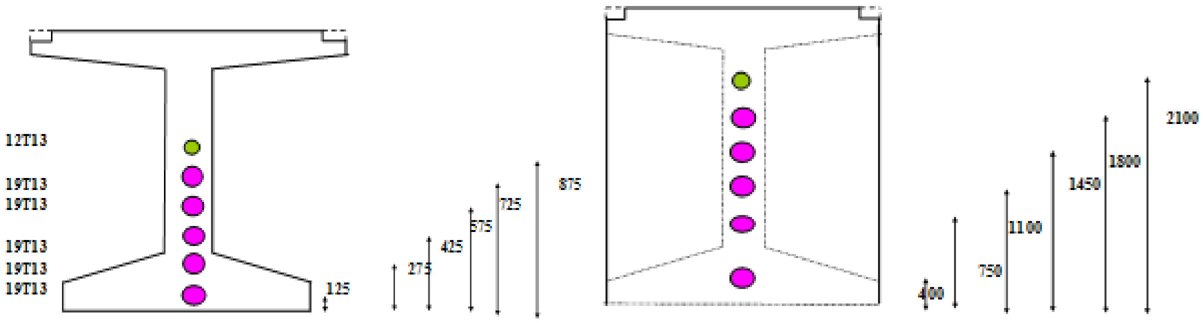

Fig. 5 Cross section of I girder with cable

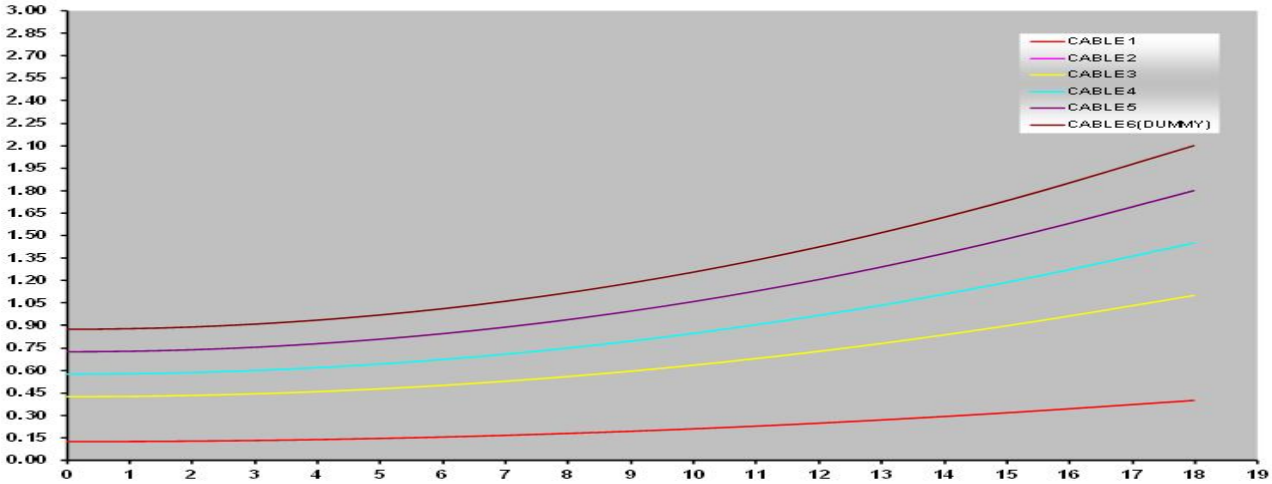

Fig. 6 Cable profile for I girder: length/height

- For box girder 4 groups of 19T13 cables are used .In this 10 nos of 19T13 cables at the top flange of box are the continuity cable. The remaining group i.e. group 2, 3 & 4 have 6 nos of 19T13 cable each. The cable ordinates, cable profile, losses due to friction and slip, are calculated and forces in each cable after this losses also found out. Here prestressing is carried out in two different stage, In first stage group 2, 3 &4 are stressing after the casting of girder. And second stage i.e. group 1 is carried out after the stich and I girder in position before service condition.

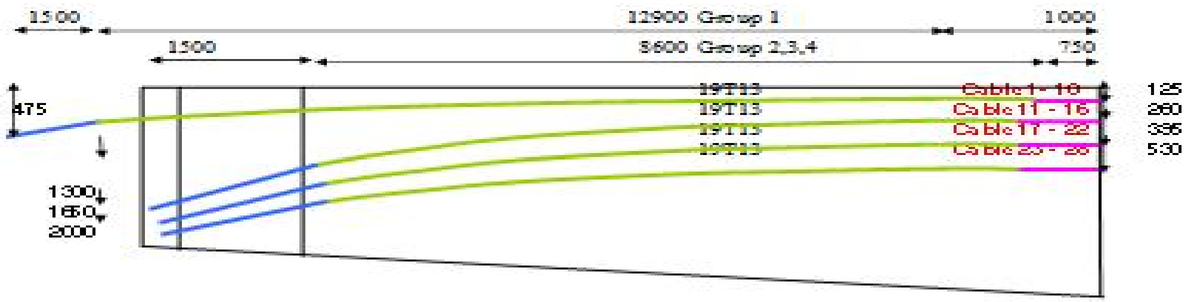

Fig. 7 Half section of box girder with cable

- Stresses at each sections are calculated for both I girder and box girder. Loss due to friction and slip and time dependent losses like elastic shortening, shrinkage, creep and relaxation are also found out at each stage of stressing. Stress checks are carried out both in the temporary stages and in the service conditions according to IRC.
- Stress diagram at service condition for both I girder and box girder are shown below

Fig. 8 Stress at section 6-6 (I girder)

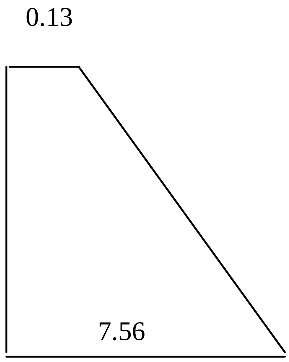

Fig. 9 Stress at section 12-12 (Box girder)

VI. RESULTS

- Modelling and analysis of the bridge is carried out in Midas civil. Bending moment and shear force due to dead load, live load, superimposed loads, temperature rise and fall, settlement, creep, shrinkage and hyperstatic effects are found out from Midas output. Diagrams of bending moment and shear force due to dead load from Midas are shown below.

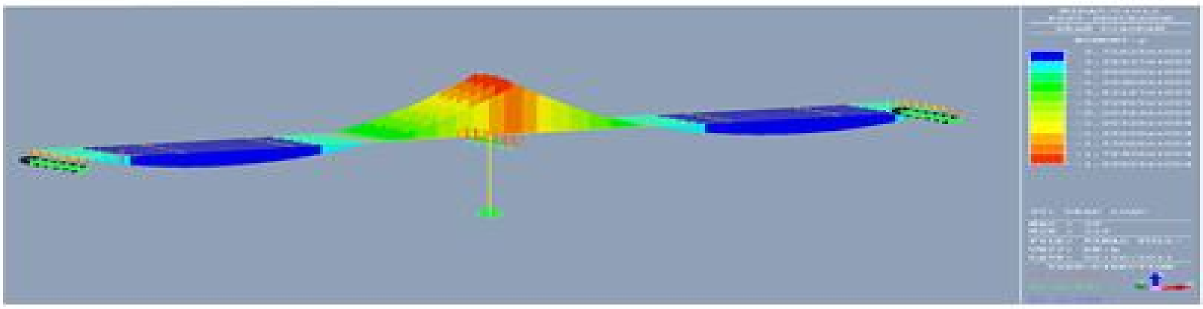

Fig.10 BMD due to dead load

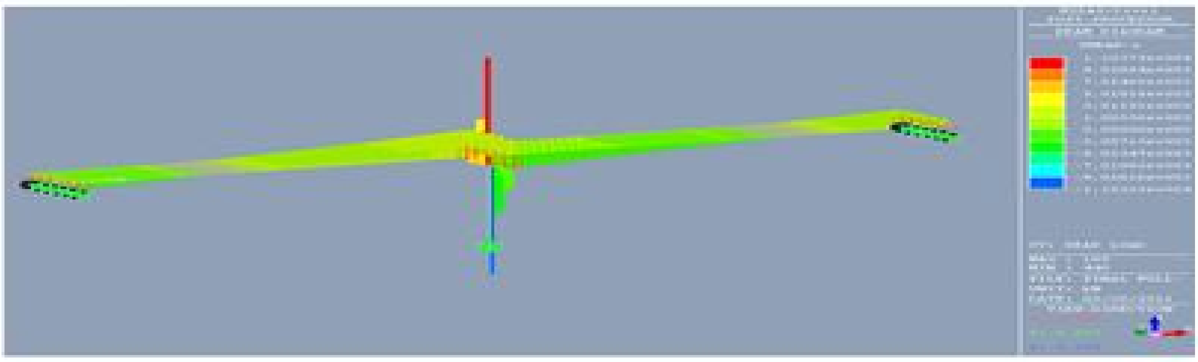

Fig.11 SFD due to dead load

- Finally a stress check for temperature and settlement are also done for service condition.
- Check for deflection and check for ultimate moment and shear are also carried out

VII. CONCLUSIONS

From the results, the following observations are made about balanced cantilever bridge:

- Less concrete, steel and formwork are required for cantilever designs.
- The reactions at the piers are vertical and central permitting slender piers.
- The cantilever design required only one bearing at every pier but in simply supported design need two bearings. Hence the width of the pier can be smaller.
- Fewer expansion bearings are needed for the full structure, resulting in lower first cost and maintenances.
- A disadvantage of this type of structure is that it requires a little more skill on the part of the designer and a more elaborate detailing of the reinforcement.

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