Seismic Analysis of Balanced Cantilever Bridge Considering Time Dependent Properties

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Abstract— **Long span bridges are generally constructed by balanced cantilever method with segmental construction. For concrete and steel the time dependent factors such as creep, shrinkage and relaxation etc. are the factors which cause high variation in stresses throughout the life of long span bridges and in such situation, seismic assessment become critical and imperative**.

Earlier research has emphasized the importance of time dependent factors like creep, shrinkage and relaxation etc. in the analysis of balanced cantilever bridge, however the present codes and authorities in this field suggests the lump sum provisions, leading to inadequate estimation of residual strength/service stress which may lead to critical condition. If such bridges are subjected to earthquake forces/actions, the criticality could be higher and leading to unacceptable condition. Therefore, the analysis should be updated /carried out considering the combined impact of time dependent properties and seismicity. Such studies are scanty or unknown and hence a study of seismic behavior of balanced cantilever bridge with consideration of time dependent factors is carried out.

The outcome of this study is reported such as, impact of time dependent factors and seismicity on analysis of balanced cantilever bridge and its comparison with conventional methods of analysis. The combined impact of seismicity and time dependent properties of the design moment of balanced cantilever bridge is studied.

Keywords—Balance Cantilever Bridge, Time History Analysis, Creep, Shrinkage, Relaxation, Moment variation

INTRODUCTION

The method is useful for bridge site where base shuttering is not possible and foundation is costly, also the method is beneficial over cable stay construction in complexity and time point of view. Concrete cantilever bridges built with the balanced cantilever method have become very popular due to the many advantages offered by the construction method and the structural form. Nowadays segmental, cast-in-place concrete cantilever bridges are routinely built for long span bridges. Use of prestressing in bridges is a vital component as they are subjected to high internal forces and stresses. For the prestressed concrete bridges segmental construction is one of the most popular techniques. Mainly advantage of this technique is elimination of false work and temporary supports by adopting the cantilever construction method which results in no objection to traffic or water way beneath the bridge. Time required for constructing multi-span bridges are more which the structure experiences continuous changes in the statical system and in support, loading and environmental conditions. Because of these conditions, the deformations and internal forces within a constructed part of the bridge changes. Due to this reason, after completion of construction is highly affected by the method and sequence of construction. Among the various parameters that affect the long term behavior of bridge structures, creep and shrinkage which are the time-dependent properties of concrete and prestressed steel have the greatest effects on the bridge behavior during and after construction. Changes in deflection and stresses are strongly affected by creep and shrinkage of concrete and relaxation of prestressed steel.

The balanced cantilever construction method is the complex method of bridge construction in which spans are constructed in cantilever manner and made continuous after completion of construction. Thus, the moments developed in the span and at support during construction, after completion of construction and in entire service life did not remain constant due to developed continuity and other factors. The time dependent material properties and seismicity are two major influencing factors on the analysis and design of balanced cantilever bridge. Thus it is again become necessary to study the combined effect of time dependent material property variation and seismicity on the analysis of balanced cantilever bridge. Or broadly it can be stated that it is very important to study the behavior or response of balanced cantilever bridge when earthquake occur at various time stages of life span of balanced cantilever bridge. This life span can include period of immediately after completion of construction, at any stage of service life of the bridge and after long time at end of life span of the bridge.

OBJECTIVES

In this paper time dependent seismic analysis study of balanced cantilever bridge is carried out on one balanced cantilever bridge model with following steps: 1. The variation in response i.e. moment, stresses etc. during construction and at various time stages during life span of the bridge under constant loads i.e. self-weight, so as to observe the effect of time dependent material properties. 2. Study of the various conventional methods of long term moment calculation for design of balanced cantilever bridge. 3. Compare the results of analysis carried out with

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software and results from conventional methods, and comment. 4. Perform the seismic analysis of balanced cantilever bridge at various time stages of life span of the bridge with consideration of time dependent properties. 5. To study the variation of response i.e. moment, stresses, deflection etc. during various staged seismic analysis. 6. Comment on final moment to be considered for design, reversal of moment etc. 6. To study the conventional methods of time dependent seismic analysis and compare the design moment obtained from these methods with detailed analysis carried out.

MOMENT VARIATION WITH TIME

The time-dependent behavior of a balanced cantilever bridge can be described using a double cantilever with an open joint at the point B, as in *fiureg.1* When the uniformly distributed load of q is applied on the structure, the elastic deflection of $\delta=ql^4/8EI$ and the rotation angle of $\alpha=ql^3/6EI$ occur at the ends of the cantilever *figure 1. b*, where l and EI refer to the length of the cantilever and the bending stiffness respectively.

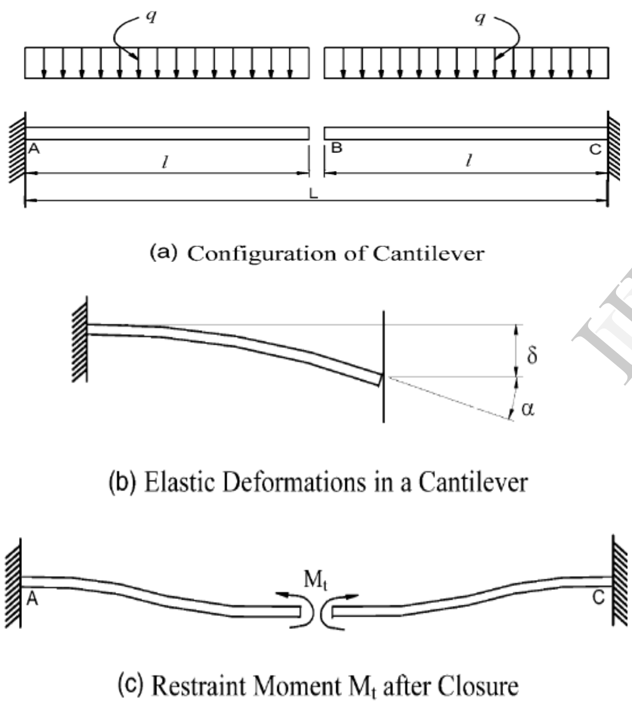

Fig.*1* Deformation of cantilevers before and after closure

If the joint remains open, then the deflection at time t will increase to $\delta\cdot(1+\phi_t)$ and the rotation angle to $\alpha\cdot(1+\phi_t)$, where ϕ_t is the creep factor at time t. However, if the joint at the point B is closed after application of the load, an increase in the rotation angle $\alpha\cdot\phi_t$ is restrained, and this restraint will develop the moment M_t, as shown in *fig.1.c*.

The moment M_t, if acting in the cantilever, causes the elastic rotation at the point B, defined as $\beta=M_t l/EI$, and also accompanies the creep deformation. Since the creep factor increases by $d\phi_t$ during a time interval dt, the variations in the angles of rotation will be $\alpha\cdot d\phi_t$ and $d\beta$ (the elastic deformation) $+\beta\cdot d\phi_t$ (the creep deformation) for α and β, respectively.

From these relations and the fact that there no net increase in discontinuity after the joint is closed, the compatibility condition for the angular deformation $(\alpha\cdot d\phi_t=d\beta+\beta\cdot d\phi_t)$ can be constructed. The integration of this relation with respect to ϕ_t gives the restraint moment

$$M_t = ql^2\frac{(1-e^{-\phi_t})}{6} = qL^2\frac{(1-e^{-\phi_t})}{24} \qquad (1)$$

Where, ϕ_t means the creep factor at time t, and $L=2l$.

From above equation, it can be found that for a large value of ϕ_t, the restraint moment converges to $M_t=qL^2/24$, which is the same moment that would have been obtained if the joint at the point B had been closed before the load q was applied. This illustrates the fact that moment redistribution due to concrete creep following a change in the structural system tends to approach the moment distribution that relates to the structural system obtained after the change from *figure 2*.

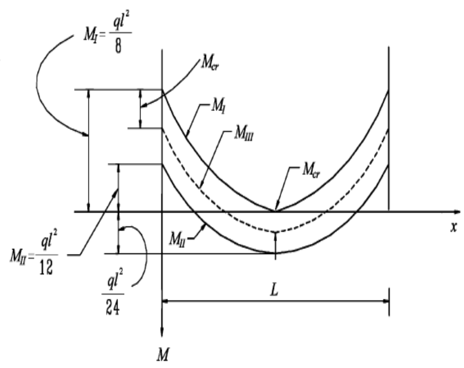

Fig. 2 Moment Variation with time

Where M_{cr} = the creep moment resulting from change of structural system, M_I = the moment due to loads before a change

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of structural system, M_{II} = the moment due to the same loads applied on the changed structural system, and M_{III}= the restraint moment M_t.

TIME DEPENDENT CONSTANT LOAD ANALYSIS:

CONVENTIONAL METHODS

The basic conventional method to consider time dependent effect is *Dischinger's Equation*. Based on this equation other two equations are developed further, which are *Trost and Wolff Equation* and *Kwak and Son Equation*. Let's discuss these methods in detail.

DISCHINGER'S EQUATION

Moment Variation with Time, leads to following final equation

$$M_{cr}= M_{III} - M_I = (M_{II} - M_I)(1-e^{-\phi t}) \qquad (2)$$

Where,

M_{cr} = the creep moment resulting from change of structural system,

M_I = the moment due to loads before a change of structural system,

M_{II} = the moment due to the same loads applied on the changed structural system,

M_{III}= the restraint moment M_t.

The above equation is most basic and widely used for calculation of time dependent moment variation.

TROST AND WOLFF EQUATION

Generally, construction of a Multiplan continuous bridge starts at one end and proceeds continuously to the other end. Therefore, change in the structural system is repeated whenever each cantilever part is tied by concreting a key segment at the midspan.

Moreover, the influence by the newly connected span will be delivered into the previously connected spans so that there are some limitations in direct applications of Dischinger's Equation to calculate the restraint moment at each span because of the many different connecting times. To solve this problem and for a sufficiently exact calculation of the final time-dependent moments, *Trost and Wolff* proposed a relation on the basis of the combination of elastic moments ($\sum M_{S,i}$; equivalent to M_I in Dischinger's Equation) occurred at each construction step,

$$M_T = \sum M_{S,i} + (M_E - \sum M_{S,i})\frac{\phi_t}{1+\rho\phi_t} \qquad (3)$$

Where, ϕt and ρ represent the creep factor and corresponding relaxation factor, respectively.

KWAK AND SON EQUATION

With the background for the time-dependent behavior of a cantilever beam effectively describing the internal moment variation in balanced cantilever bridges, and by maintaining the basic form of equation suggested by *Trost and Wolff*, considering the construction sequence while calculating the internal moments at an arbitrary time *t*, the following relation is introduced by *Kwak and Son*

$$M_T = \sum M_{S,i} + (M_E - \sum M_{S,i})(1-e^{-(\phi_t-\phi_c)})\cdot f(\phi_t) \qquad (4)$$

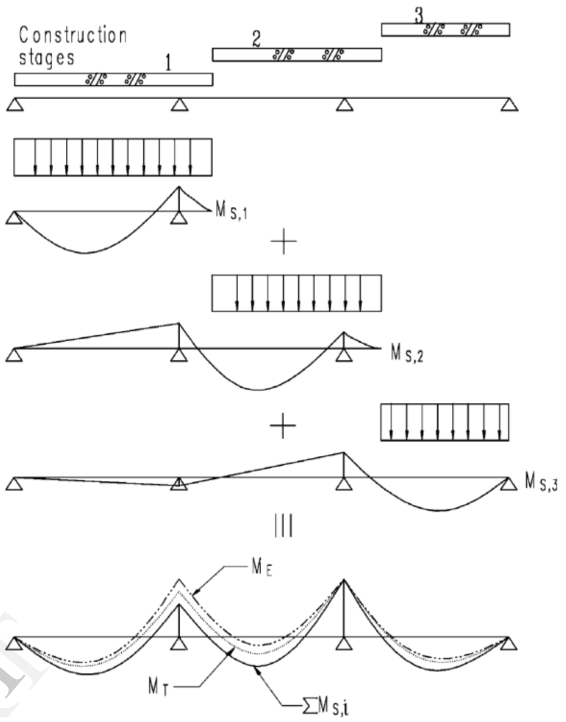

Fig.3 Combination of $M_{s,i}$

Where, $f(\phi_t)=\chi\,\phi_t\,/\,(1-\chi\,\phi_t)$. χ is the concrete aging coefficient which accounts for the effect of aging on the ultimate value of creep for stress increments or decrements occurring gradually after application of the original load. It is reported in the study carried out by Kwak and Son that an average value of c=0.82 can be used for most practical problems where the creep coefficient lies between 1.5 and 3.0.

Out of the above three formulae, *Trost and Wolff* equation is not directly applicable to the balanced cantilever bridge, thus moment variation according to other two conventional formulae are studied for the present Balance Cantilever Bridge Model and it is compared to the exact analysis carried out in the SAP2000 according to CEB-FIP code.

PROBLEM STATEMENT

The Cantilever Bridge having 2 piers and 3 spans.
Total Length of span= 149 m
Span 1= 44 m
Span 2= 61 m
Span 3= 44 m
Width of Span = 13.2 m
Slab thickness
Top slab (t_1) = 0.225 m
Bottom slab (t_2) = 0.225 m
External Girder (t_3) = 0.431 m.

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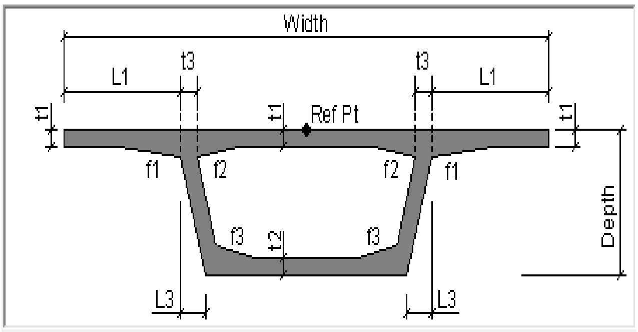

Fig. 04 Cross section of Deck

CONSTANT LOAD ANALYSIS RESULTS

The span moment and support moment of present balanced cantilever bridge model is calculated at various time stages of life span with the current formulae. Since, there are limitations in direct applications of Trost and Wolff Equation to balanced cantilever bridge, only Dischinger's equation and Kwak and Son's equation is considered for conventional method of time dependent content load analysis. The moments coming from formulae and from analysis carried out from SAP 2000, is compared and presented in the graphs bellow.

Horizontal axis represents time in Days, vertical axis represents Moments

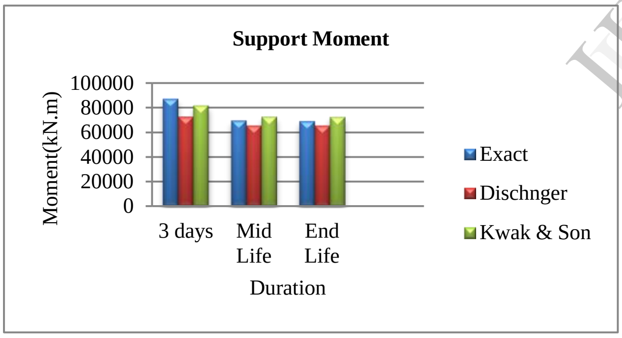

Fig.05 Moment Variation Calculation – Support Moment. (kN·m)

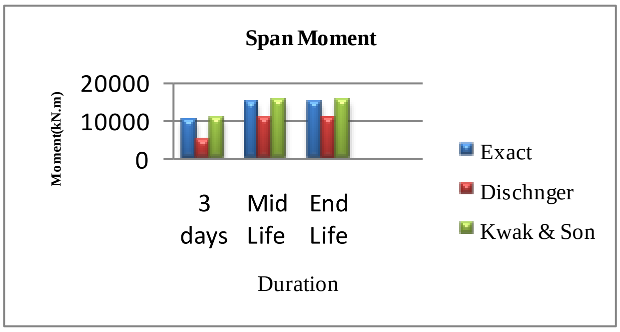

Fig.06 Moment Variation Calculation – Span Moment. (kN·m)

SEISMIC ANALYSIS

The time elapsed stage considered to include the effect of time dependent material properties are 7 days after completion of construction, 10 years, 50 years and 100 years after completion of construction. After the 7 days of completion of construction acceleration time history is applied to Z direction of the bridge individually. Similarly, the time history is applied to other time stages (10 years, 50 years and 100 years after completion of construction.)

PROBLEM STATEMENT

The earthquake occurred on January 26, 2001 at Kachchh region, Gujarat, with magnitude of 7.0. This event is recorded at 1 accelerograph station at Ahmadabad. Following is details of ground motion:

- Origin Time – 08:46:42.9 IST
- Epicenter – 23.40^0N, 70.28^0E
- Focal Depth - 25 km

Table 1 Time History Data

Recording Station	Direction	R (km)	PGA (g)
Ahmadabad (23.40^0N, 70.28^0E)	Lateral	238.0	0.106
	Transverse	238.0	0.080
	Vertical	238.0	0.070

Three time history data files are available with details described above, out of two horizontal time history data maximum PGA i.e. peak ground acceleration data is applied to both lateral and transverse direction of the bridge.

The moment variation in span and support due to earthquake analysis is represented from the bar charts bellow. On the bar chart X axis represents time of application of earthquake i.e. 7 days, 10 years, 50 years and 100 years after completion of construction. Y axis represents corresponding moments (span moment or support moment.) Out of the three bars, central red bar represents the variation in moment due to constant load only at time stages of 7 days, 10 years, 50 years and 100 years after completion of construction. The green and blue bars represents the maximum and minimum moment developed from earthquake analysis.

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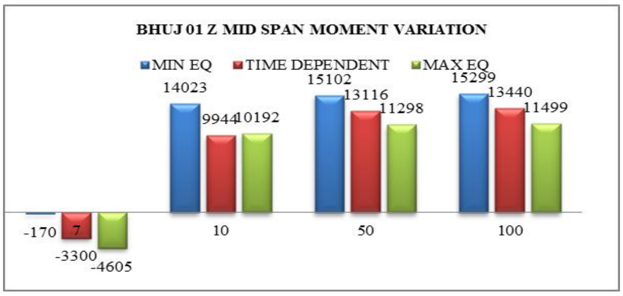

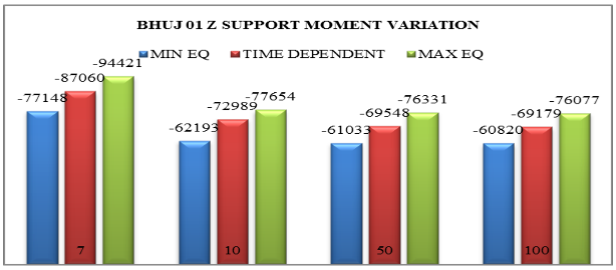

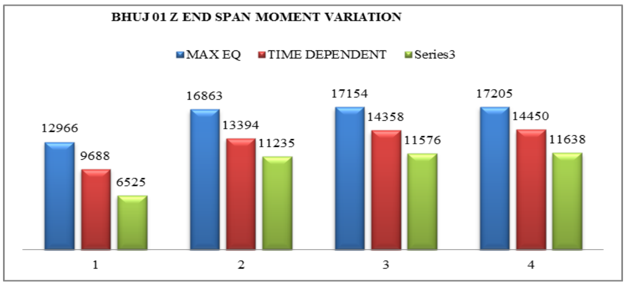

Fig.07 Moment variation comparison due to Bhuj, Jan 01 earthquake in Z direction.

CONCLUSION

Constant load analysis (Conventional method)

Table 02: The Dischinger's equation is compared with detailed analysis

No. of Days	3	18000	36000
Support Moment	17%	14%	6%
Span Moment	16%	27%	28%

Table 03: The Kwak and Son's equation with detailed analysis

No. of Days	3	18000	36000
Support Moment	6%	5%	4.8%
Span Moment	7%	3.5%	3%

Conventional methods of time dependent analysis are studied and moment calculations were carried out for the bridge as described. The results are compared with detailed analysis carried out, the following observations,

1.The Dischinger's equation is compared with detailed analysis carried out and it was found that for support moment, it differs by 17%, 14% and 6% at initial time of life span, middle of life span and end of the life span respectively.

2. For span moment the Dischinger's equation differs by 16%, 27% and 28% at initial time of life span, middle of life span and end of the life span respectively when compared with detailed analysis carried out.

3. When Kwak and Son's equation is compared with detailed analysis carried out and it was found that for support moment, it differs by 6%, 5% and 4.8% at initial time of life span, middle of life span and end of the life span respectively.

4. For span moment the Kwak and Son's equation differs by 7%, 3.5% and 3% at initial time of life span, middle of life span and end of the life span respectively when compared with detailed analysis carried out.

5. Hence it can be concluded that the results derived by Kwak and Son's equation are in closed agreement with detailed analysis carried out.

Table 04: Combined seismic and time dependent analysis.

Moment kN.m	7 Days	10 Years	50 Years	100 Years
Support	17273	15462	15298	15257
End Span	6441	5628	5578	5567
Mid Span	4435	3831	3804	3800

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1. For support moment the difference in minimum and maximum earthquake response at 7 days is 17273 kN·m, that for 10 years is 15462 kN·m, for 50 years 15298 kN·m, and for 100 years earthquake difference is 15257 kN·m. This difference is due to time dependent property effect.
2.For End Span Moment the difference in minimum and maximum earthquake response at 7 days is 6441 kN·m, that for 10 years is 5628 kN·m, for 50 years 5578 kN·m, and for 100 years difference is 5567 kN·m.
3. For Mid Span Moment the difference in minimum and maximum earthquake response at 7 days is 4435 kN·m, that for 10 years is 3831kN·m, for 50 years 3804 kN·m, and for 100 years difference is 3800 kN·m.

The above study concludes that there is significant effect of time dependent properties on seismic analysis of balanced cantilever bridge. Thus detail analysis of each bridge constructed by balanced cantilever method must be analyzed considering time dependent properties.

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