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Design and Analysis of Bridge Foundations with and Without Linear Soil Interaction

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Abstract - The foundation of a structure resting on a settable soil mass undergoes differential settlement which alters the forces in the structural elements substantially. An inflexible-frame Bridge is a bridge wherein the superstructure and substructure are rigidly related to appearing as a continuous unit. Usually, the shape is solid monolithically, making the shape non-forestall from deck to the muse. The connections between people are rigid connections which switch bending second, axial forces, and shear forces. A bridge layout together with a rigid frame can offer giant structural benefits, but additionally can be tough to layout and/or bring together. The linear or nonlinear behavior of soil mass is the essential motive of differential settlement which redistributes the forces within the factors of the form, especially in the superstructure.

In the case of the engineering technology systems, foundation entails with direct touch with the floor. Once the external forces like earthquake act on those systems, the structural displacements and also the floor displacements are freelance of each other. The approach for the duration of which the reactions of the soil impact the motion of the structure and add the motion of the structure impacts the response of the soil is named as Soil-shape interaction (SSI). The biggest uncertainty inside the fashion of these bridges is that the reaction of the soil in the back of the abutments and next to the foundation piles, mainly during thermal enlargement. This lateral soil reaction is non-linear and could be performed of the importance and nature of the wall displacement.

Keywords – Linear Soil, Bridge, Design.

I. INTRODUCTION

The foundation of a structure resting on a settable soil mass undergoes differential settlement which alters the forces in the structural elements appreciably. A rigid-body Bridge is a bridge in which the superstructure and substructure are rigidly related to acting as a continuous unit. Generally, the structure is solid monolithically, making the structure non-stop from deck to the foundation. The connections between individuals are rigid connections which transfer bending second, axial forces, and shear forces. A bridge design together with an inflexible frame can provide giant structural blessings, however also can be difficult to layout and/or assemble. The linear or nonlinear conduct of soil mass is principal motive of the differential agreement which redistributes the forces within the elements of the form specifically within the superstructure.

In the case of the engineering science structures basis entails with direct touch with the floor. Once the external forces like earthquake act on these systems, the structural displacements and additionally the floor displacements is freelance of each other. The method at some stage in which the reaction of the soil impacts the movement of the shape and add the motion of the structure impacts the response of the soil is named as Soil-structure interplay (SSI).

Conventional Method of Analysis:

In the customary strategy for outline of a multistoried building, the structure is composed as a free edge accepting immovable backings, and the impacts of soil-establishment are ignored. In any case, in genuine soil conditions, such an investigation may frequently prompt unlikely and dangerous as the firmness of the structure can be limited the removals of the establishments and even little differential settlements of the establishments may likewise adjust the powers of the basic individuals essentially. This redistribution of strengths may cause the disappointment of the structure. It is in this way important to considered building casing, establishment and soil as single indispensable perfect basic unit for practical examination of the framework.

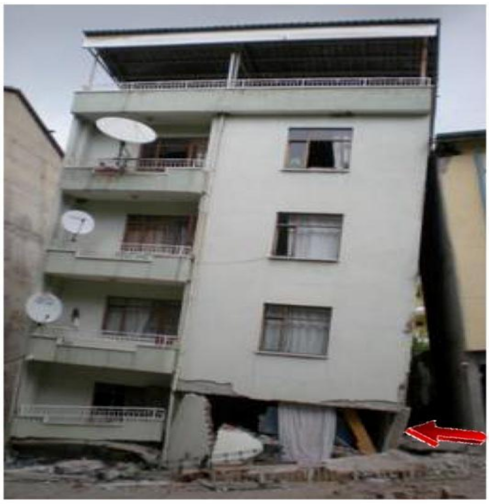

Figure 1: Failure due to differential soil settlement

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Soil-Structure Interaction

Since 1960's, soil-shape interaction (SSI) has been diagnosed as a crucial element which can substantially have an effect on the relative reaction of constructing, the motion of basis and movement of soil on which shape is rested.

Soil-structure interaction mainly can be divided into two types:

a) Kinematic interaction

b) Inertial interaction.

(a) **Kinematic interaction**: The establishment of the structure which is refreshed on the dirt won't take after the free field movement. This failure of the establishment to coordinate the free field movement causes the kinematic connection. The disfigurement due to kinematic cooperation alone can be controlled by accepting the solidness of the establishment without considering soil mass as appeared in Figure. 1.1. The condition of movement for this case is

$$[M_{soil}]\{\ddot{u}_{KI}\} + [C]\{\dot{u}_{KI}\} + [k^{*}]\{u_{KI}\} = -[M_{soil}]\{\ddot{u}_{gs}\}$$

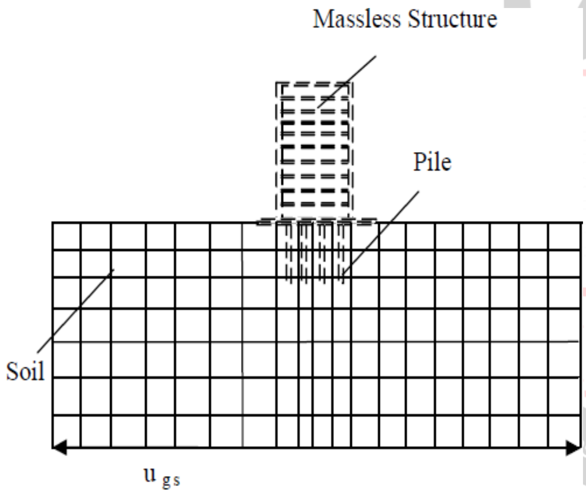

Figure 2: Kinematic Interaction

(b) **Inertial interaction**: When it is accepted that the mass of the superstructure exchanges the inertial constraint to the dirt and this will bring on additional distortion in the dirt, at that point the cooperation is named as an inertial association. The structure and establishment (Figure. 1.2) do have mass and this mass makes them react progressively. The miss happening because of this kind of cooperation can be resolved from the accompanying condition of movement

$$[M]\{\ddot{u}_{II}\} + [c]\{\dot{u}_{II}\} + [k^{*}]\{u_{II}\} = -[M_{structure}]\{\ddot{u}_{KI} + \ddot{u}_{gs}\}$$

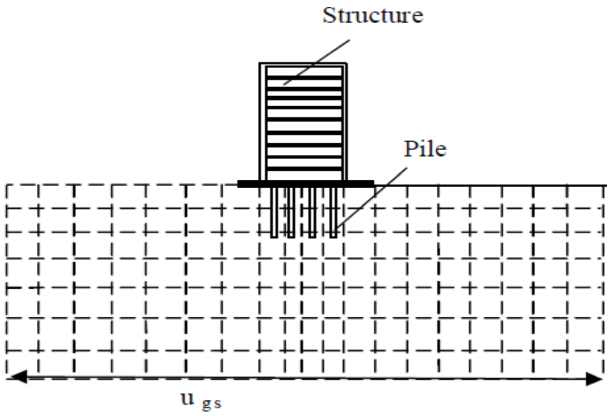

Figure 3: Inertial Interaction

Where $[M_{structure}]$ is the mass matrix assuming soil is massless ; $[k^{*}]$ is Stiffness of entire system ; $[c]$ is Damping matrix of entire system ; $\ddot{u}_{gs}$ Input Ground Acceleration ; and u_{II} Displacement due to inertial interaction

Methods of evaluation of Soil Structure Interaction:

➢ **Direct Approach:**

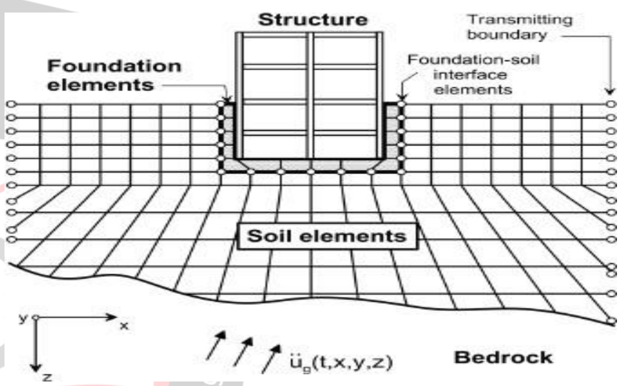

Figure 4: Direct Approach of Soil Structure Interaction

➢ **Substructure Approach:**

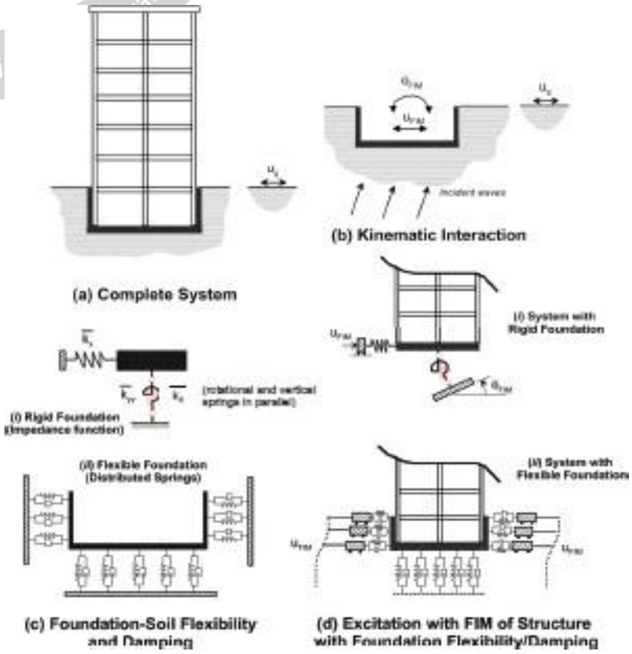

Figure :5 Substructure Approach of Soil Structure Interaction

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Effect of Soil Structure Interaction on a building:

- The dynamic interaction between superstructure and base may be classified into components: inertial interaction and kinematic interplay. Early SSI improvement becomes prompted by way of the seismic layout of nuclear power plant life.

Soil Properties:

Table 1: Typical Mass Densities of basic type of Soils

S. No.	Type of Soil	Mass Density (g/m^3)			
		Poorly Graded Soil		Well Graded Soil	
		Range	Typical Value	Range	Typical Value
1	Loose sand	1.70–1.90	1.75	1.75–2.00	1.85
2	Dense sand	1.90–2.10	2.07	2.00–2.20	2.10
3	Soft clay	1.60–1.90	1.75	1.60–1.90	1.75
4	Stiff clay	1.90–2.25	2.00	1.90–2.25	2.07
5	Silty soils	1.60–2.00	1.75	1.60–2.00	1.75
6	Gravelly soils	1.90–2.25	2.07	2.00–2.30	2.15

(i) **Poisson Ratio:**

Table 2: Typical Values of poisson ratio for soils

S. No.	Type of Soil	Poisson ratio
1	Clay (saturated)	0.4 – 0.5
2	Clay (unsaturated)	0.1 – 0.3
3	Sandy clay	0.2 – 0.3
4	Silt	0.3 – 0.35
5	Sand (dense)	0.2 – 0.4

(ii) **Elastic modulus:**

Table 3: Typical values of Elastic Modulus of Various Soils

S. No.	Type of Soil	us of Elasticity (Es) N/mm^2
1	Clay	
1.1	Very soft	2–15
1.2	Soft	5–25
1.3	Medium	15–50
1.4	Hard	50–100
1.5	Sandy	25–250
2	Glacial till	
2.1	Loose	10–153
2.2	Dense	144–720
2.3	Very dense	478–1,440
2.4	Loess	14–57
3	Sand	
3.1	Silty	7–21
3.2	Loose	10–24
3.3	Dense	48–81
4	Sand and gravel	
4.1	Loose	48–148
4.2	Dense	96–192
4.3	Shale	144–14,400
4.4	Silt	2–20

Modulus of subgrade reaction: Mathematically the modulus of subgrade reaction may be expressed as

$$Ks = p/s$$

Where p = constant pressure intensity

s = soil settlement

Table 4: Typical Values of Ks for soils

S. No.	Type of Soil	Ks (kN/m^3)
1	Loose sand	4,800–16,000
2	Medium dense sand	4,800–16,000
3	Dense sand	64,000–1,28,000
4	Clayey medium dense sand	64,000–1,28,000

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5	Silty medium dense sand	64,000–1,28,000
6	Clayey soil: qu < 200 N/mm2 200 < qu <400 N/mm2 qu > 800 N/mm2 > qu – Safe bearing capacity	12,000–24,000 24,000–48,000 48,000

Finite Element Method (FEM):

The Finite Element Method (FEM) is one of the strategy numerical examination of getting rough arrangements of different sorts of structures. This requires the fast electronic computerized PCs. Albeit initially created to think about worries in complex airframe structures, it has been stretched out and connected to the expansive field of continuum mechanics. It is getting much significance in the field of designing because of its assorted qualities and adaptability as an examination device.

In this strategy for the limited component, the structure is isolated from littler components of limited measurements called 'limited components'. The first structure is then considered as a blend of these components in which the joints of these components are called 'hubs'.

The properties of the components are detailed and joined to get the answer for the whole structure. The shape capacities have approximated the variety of dislodging inside a component as far as relocation at the hubs of the component. The strains and worries inside a component will likewise be communicated as far as the nodal dislodging. The guideline of virtual uprooting is utilized to determine the conditions of harmony for the component and the nodal relocation will be the questions in the conditions.

The limit conditions are forced and the conditions of balance are settled for the nodal relocation. From the estimations of the nodal uprooting for every component, the anxieties and strains are assessed utilizing the component properties.

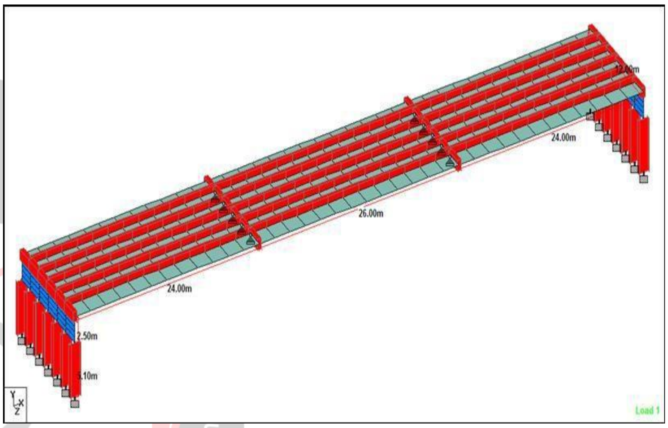
Along these lines, rather than taking care of the issue of the whole structure in one operation, in this Finite Element Method consideration is chiefly committed to the detailing of the properties of the constituent components.

Software based on finite element method- Staad-Pro:

Staad-Pro is a basic examination and outline PC program initially created by Research Engineers International in Yorba Linda, CA. In late 2005, Research Engineer International was purchased by Bentley Systems. A more seasoned adaptation called Staad-III for Windows is utilized by Iowa State University for instructive purposes for common and basic architects. The business form staad-expert is a standout amongst the most broadly utilized basic examination and plan programming. It bolsters a few steel, cement and timber configuration codes. It can make utilization of different types of examination from the conventional first request a static investigation, second request p-delta investigation, geometric nonstraight examination or a clasping examination. It can likewise make utilization of different types of dynamic investigation from modular extraction to time history and reaction range examination.

II. PROBLEM FORMULATION

The objective of the prevailing paintings is to examine the behaviour of the rigid frame bridge below diverse load mixtures of dead load, live load and thermal hundreds various from 100C to 500C with 10ºC upward thrust with each load case carried out for the duration of the bridge deck in the longitudinal route. The stay load is applied as in keeping with IRC 6-2000 the use of STAAD-Beava (Bridge Engineering automated car software). Right here the software program routinely calculates the vehicle load and no of lanes de-pending upon the carriage manner width as per the codal provisions.



Deck Slab-Length: 74m; Width: 12m; Thickness: 0.24m
Abutment-Height 2.5m; Width: 12m; Thickness: 1.25m
Girders-Longitudinal girder: 5 no's (0.35m X 1.5m) **Cross girder**- 4 no's (0.5m X 1.0m)

Piles-No's 7; Height: 5.0m

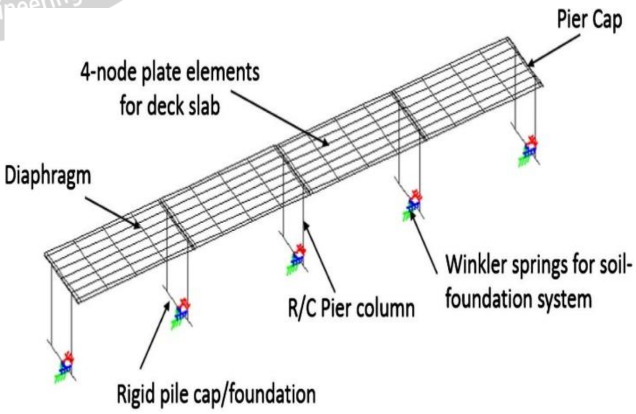


Fig 6 RFB STRUCTURAL MODELLING

III. METHODOLOGY

RIGID FRAME BRIDGE STRUCTURAL AND MATERIAL MODELLING

The structural factors of the bridge are modeled as linear

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factors while the soil reaction adjoining to the piles and at the back of the abutment walls are modeled as non-linear guide springs. The three-D version of the shape contains:

i. The superstructure which includes concrete slab acting in composition with five longitudinal girders and 4 cross beams, one at every give up of the span.

ii. The deck slab has modeled the use of plate elements and the girders as beam factors. The intermediate piers being dealt with as simple curler supports.

iii. the two.5 m high abutment modeled as plate factors. The soil in the back of the abutment and across the piles modeled as multi-linear springs.

iv. Seven steel piles with full fixity are linked to every abutment partitions, permitting full second switch. Each pile is modeled as beam element with a not unusual node for the pile and the abutment wall using structural evaluation software, STAAD.pro V8i.

Spring Stiffness Calculations for Abutment structure

NCHRP curves relate the horizontal normal stress σ'h to the vertical effective normal stress σ'v according to σ'h = K σ'v where for a uniform density dry soil σ'v = γz, where γ = dry density of soil.

To calculate the effective soil spring resistance for input into the bridge model, the effective panel size of each wall element is computed using dimension as used in the model. Typical interior panels are of width w =2m and height h= 0.5m. This area is multiplied by the effective vertical normal stress σ'v for a given panel depth z and by the lateral earth pressure co-efficient K for a given deflection to yield a lateral force – deflection curve for a given node

F = K σ'v w h (6)

Where σ'v = γz

σ'v = vertical normal stress z = panel depth

w = width of plate as used in model h= height of plate as used in model

K=Earth pressure coefficient versus relative wall displacement

Spring Stiffness Calculation for Piles

As earlier stated the soil resistance p is given by equation

$$p = tanh\left[\frac{k1z}{A\ pu}\ y\right] A\ pu$$

And the force-displacement relation is given by

$$F = A\ pu \tanh\left(\frac{k1zy}{Apu}\right) Lp$$

Where,

A= 0.9 is introduced for cyclic loading (= 3.0 − 0.8 (z/D) ≥ 0.9)

F= force in spring

pu = ultimate soil resistance (lower of pus or pud) pus = shallow ultimate resistance

pud = deep ultimate resistance

k1 = initial soil stiffness chosen for a given of friction Φ

z = soil depth from the bottom of approach slab to the spring y = horizontal displacement

Lp = length of beam element

The ultimate soil resistances are given as pus = (c1 z + c2 D) γ' z

pud= c3 γ' D z where,

γ' = dry density of soil adjacent to piles Φ = angle of internal friction in sand

c1, c2, and c3 are coefficients as functions of Φ, and

c1 = k0 tan(□) sin □ / tan(□ - □) cos(□) + tan^2 □ tan(□) / tan(□-□) + k0 tan □(tan(□) sin

- tan(□))

c2 = tan □ / tan (□-□) – tan^2 (45-□ / 2) c3 = k0 tan (□) tan^4 □ +k(tan^8□-1)

□= Φ/2 β= 45 + Φ/2

D = average pile diameter from surface to depth (length). ko= at rest earth pressure coefficient = (1- sinΦ)

ka= Rankine active earth pressure coefficient = tan^2 (45-Φ/2) Initial stiffness of soil= k1 Dry density of soil adjacent to piles = γ'

IV. RESULTS AND DISCUSSION

The results are compared for the bending moments, deflection and shear force for the central and end longitudinal girder and deck slab and are presented in the form of graphs considering the effects of soil for RFB's.

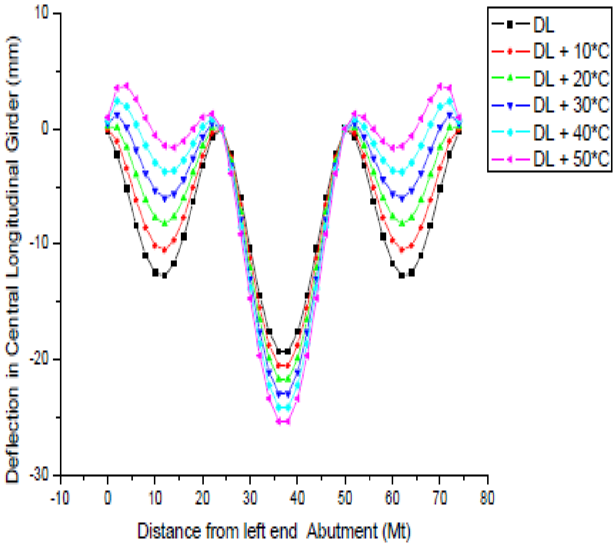

Fig.7: Deflection in longitudinal central girder due to D.L +

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thermal load combination with soil interaction.

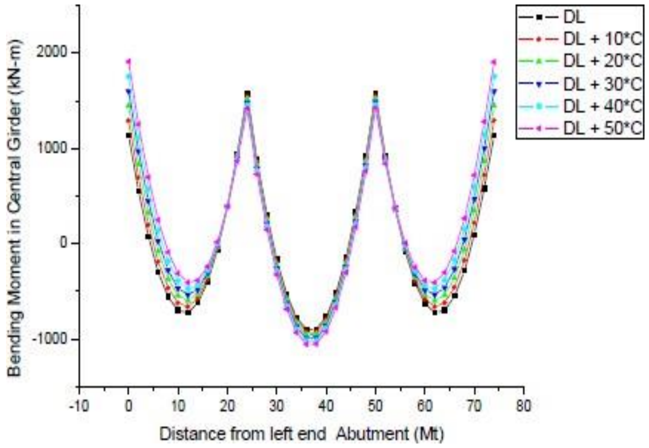

Fig 8: B.M in central longitudinal girder due to D.L + thermal load combination with soil interaction.

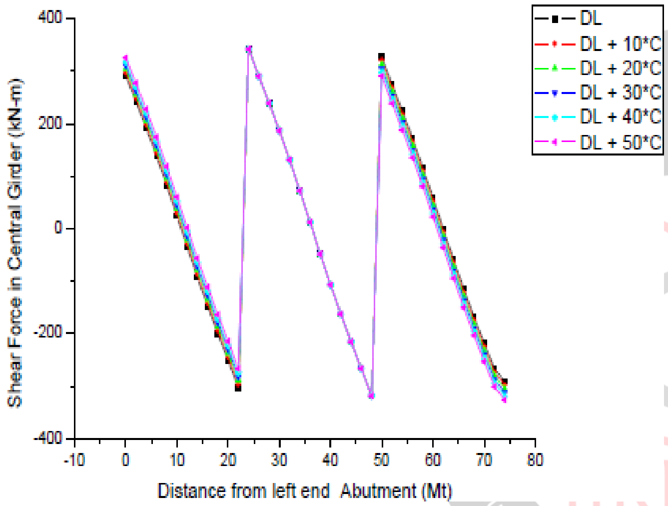

Fig 9:S.F in central longitudinal girder due to D.L+ thermal load combination with soil interaction.

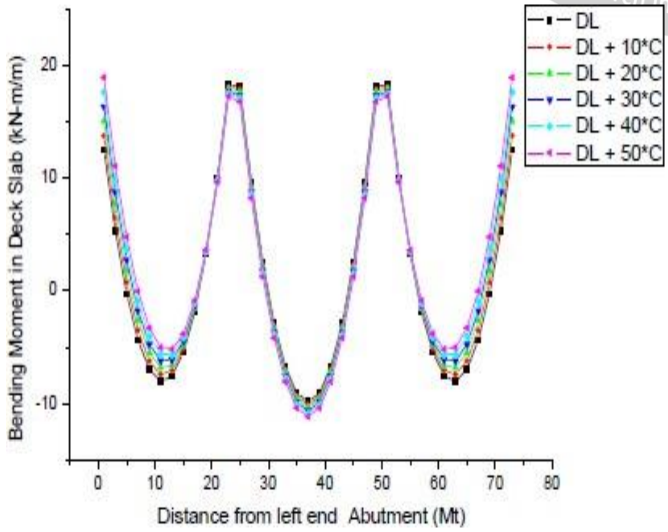

Fig 10: B.M in deck slab due to D.L+ thermal load combination with soil interaction.

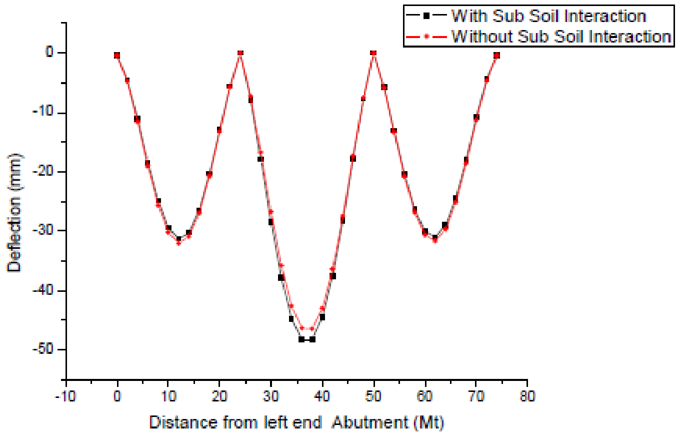

Fig 11: Comparison of deflection in central longitudinal girder due to dead load + live load with and without Soil Interaction

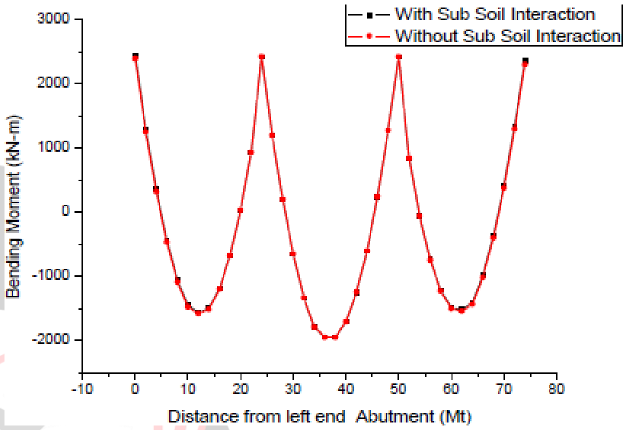

Fig 12: Comparison of B.M in central longitudinal girder due to dead load + live load with and without Soil Interaction

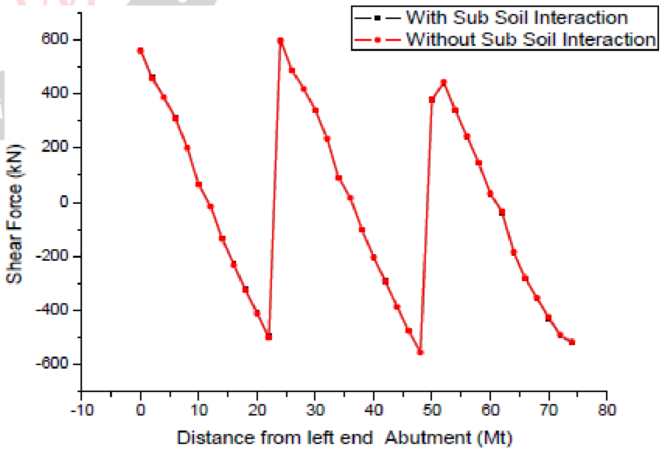

Fig 13: Comparison of B.M in central longitudinal girder due to dead load + live load with and without Soil Interaction.

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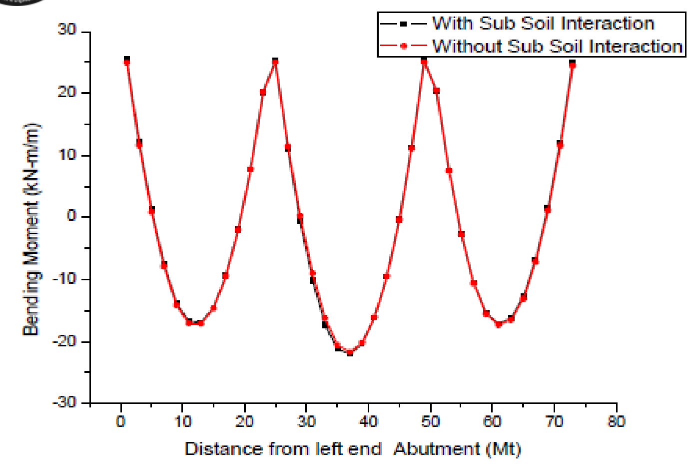
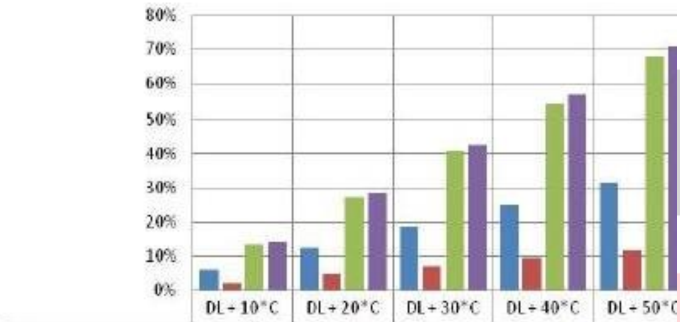
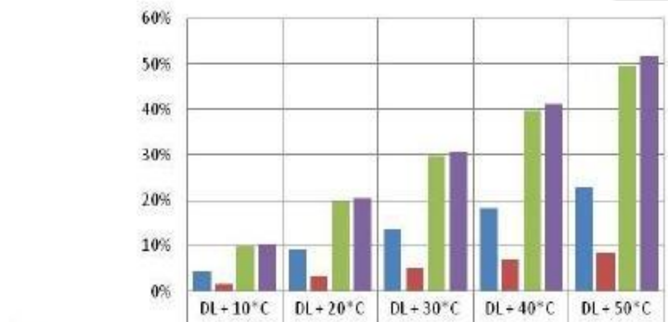


Fig 14: Comparison of S.F in central longitudinal girder due to dead load + live load with and without Soil Interaction



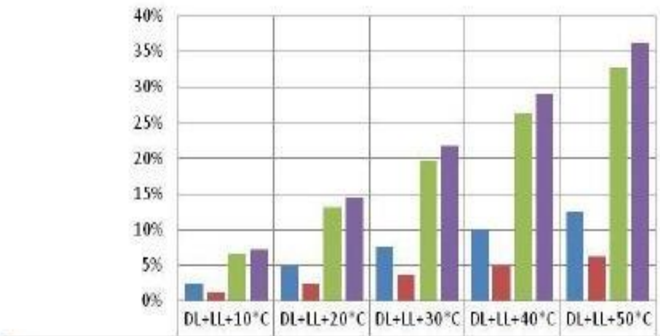
	DL+10°C	DL+20°C	DL+30°C	DL+40°C	DL+50°C
Defln in Central Girder	6.31%	12.61%	18.92%	25.22%	31.47%
SF in Central Girder	2.41%	4.82%	7.23%	9.64%	12.05%
BM in Central Girder	13.64%	27.28%	40.93%	54.50%	67.73%
BM in Deck Slab	14.22%	28.43%	42.66%	56.84%	70.77%

Fig 15: Percentage variation of Deflection, SF & BM with soil interaction for Dead Load and of Thermal Load.



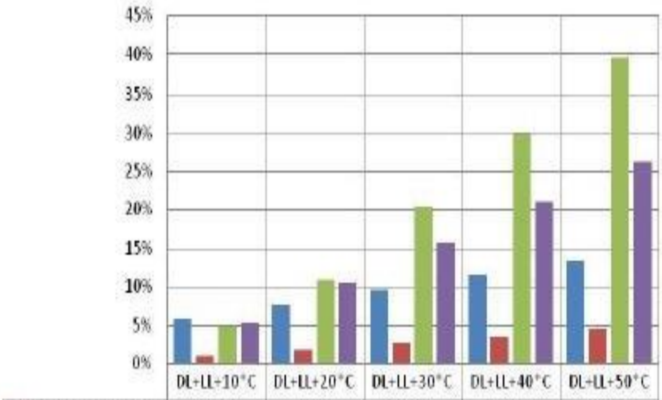
	DL+10°C	DL+20°C	DL+30°C	DL+40°C	DL+50°C
Defln in Central Girder	4.60%	9.19%	13.79%	18.38%	22.97%
SF in Central Girder	1.72%	3.43%	5.15%	6.87%	8.58%
BM in Central Girder	9.97%	19.95%	29.92%	39.90%	49.87%
BM in Deck Slab	10.33%	20.67%	30.99%	41.33%	51.66%

Fig 16: Percentage variation of Deflection, SF & BM without soil interaction for Dead Load and Combination of thermal Load.



	DL+LL+10°C	DL+LL+20°C	DL+LL+30°C	DL+LL+40°C	DL+LL+50°C
Defln in Central Girder	2.52%	5.03%	7.55%	10.07%	12.56%
SF in Central Girder	1.25%	2.50%	3.75%	4.99%	6.25%
BM in Central Girder	6.58%	13.16%	19.74%	26.29%	32.67%
BM in Deck Slab	7.26%	14.52%	21.79%	29.03%	36.15%

Fig 17: Percentage variation of deflection, SF & BM with soil interaction for D.L+ L.L and Combination of Thermal Load.



	DL+LL+10°C	DL+LL+20°C	DL+LL+30°C	DL+LL+40°C	DL+LL+50°C
Defln in Central Girder	5.78%	7.67%	9.56%	11.45%	13.34%
SF in Central Girder	0.89%	1.78%	2.67%	3.56%	4.45%
BM in Central Girder	4.81%	10.78%	20.39%	30.00%	39.61%
BM in Deck Slab	5.28%	10.55%	15.82%	21.10%	26.38%

Fig 18: Percentage variation of deflection, SF & BM without soil interaction for D.L+ L.L and Combination of Thermal load.

Percentage Change With Soil Interaction With Respect To Without Soil Interaction For D.L Condition.

		Difference		% Change
Deflection	End Girder	0.20	mm	0.83
	Central Girder	0.19	mm	1.00
Shear Force in Longitudinal Girders	End Girder	0.55	kN	0.15
	Central Girder	1.82	kN	0.63
Bending Moment in Longitudinal Girders	End Girder	-23.0 to -24.0		1.52

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		kN-m	
	Central Girder	-29.4 to 30.2 kN-m	2.59
g Moment in Deck Slab	End Plate	-0.3 to 0.5 kN-m	2.29
	Centre Plate	0.1 to 0.2 kN-m	0.60

Percentage Change With Soil Interaction With Respect To Without Soil Interaction For Dead Load +Live Load Condition

		Difference	% Change
Deflection	End Girder	1.34 mm	2.50
	Central Girder	1.94 mm	4.0
Shear Force in Longitudinal Girders	End Girder	0.88 kN	0.144
	Central Girder	3.75 kN	0.75
Bending Moment in Longitudinal Girders	End Girder	-43.9 kN-m	1.6
	Central Girder	-58.3 kN-m	2.50
g Moment in Deck Slab	End Plate	-0.57 kN-m	2.30
	Centre Plate	0.34 kN-m	1.57

V. CONCLUSIONS

Following are the conclusions primarily based at the examiner:

1) The most deflection in longitudinal girder of inflexible frame bridge is located to be greater whilst soil interplay is taken into account for all temperature ranges studied. Comparable are the observations for shear pressure and bending second in deck slab. This is due to impact of restraint furnished with the aid of stiffness of soil in the back of the abutment and around the piles.

2) There's no significant variant in bending second, shear force and deflection inside the longitudinal girder and deck slab for a specific temperature alternate for RFB (inflexible body bridge) with and without soil interaction.

3) it's far discovered that by using changing the soil residences at the back of the abutment and across the piles does now not have an effect on significantly the overall performance of deck slab in terms of B.M, S.F, and deflection.

4) The bending second and deflection in deck slab and girders will increase linearly with growth in temperature.

5) The moments on deck slab boom with an increase in temperature for essential abutment bridges.

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