ISSN 2320-9186

Global Scientific JOURNALS

GSJ: Volume 6, Issue 8, August 2018, Online: ISSN 2320-9186
www.globalscientificjournal.com

ADVANCES IN THE ANALYSIS OF SIMPLY SUPPORTED CONCRETE BRIDGE DECK

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ABSTRACT: Highways and Railways will continue to be the major transportation modes in Nigeria for the foreseeable future for the movement of people, goods and services. The intensity of the motor traffic is continuously increasing and will be further increased for some years. The analysis aims at improving on the beam and slab deck design by eliminating several joints associated with simply supported concrete decks. To accomplish these, the Guyon-Massonet-Bare method is used.

Keywords: Highways, bridge decks, construction technology, maintenance cost, girder spacings, lateral load

1 INTRODUCTION

Highways and Railways will continue to be the major transportation models in Nigeria for the forseable future for the movement of people, goods and services.

The intensity of the motor traffic is continuously increasing and will be further increased for some years. Therefore some of the existing bridge decks must be rebuilt or strengthened and new modern motorways built in order to reduce traffic congestion or eliminate long distance traffic.

Bridge deck which is the superstructure of any bridge is required to cross rivers, valleys, roads and railways at different levels. Bridge Engineering like other heavy civil engineering works offers the engineer the opportunity to apply his creative ability, knowledge of building materials technology, construction technology and applied mechanics to evolve structural forms in bridge structures which are both functional and aesthetically pleasing.

Bridge decks unlike buildings are designed to carry heavy ever changing moving load patterns during their life span. The life span of bridge decks vary from 50-100 years. The ever increasing cost of construction and maintenance calls for greater economy in bridge deck analysis, design and construction supervision.

To ascertain the different methods of analysis of a simply supported concrete bridge deck and the advances or improvement made to reduce several joints associated with simply supported bridge decks, due to the problems (disadvantages) associated with expansion joints, one has;

- to carefully understand the technical knowhow on the analysis of a simply supported concrete bridge deck with reference to the beam and slab bridge deck, and the improvement or advances made presently to eliminate too many joints at supports to give a reliable approach in terms of bridge deck configuration, economic, safety, low maintenance cost and construction method for fast project completion.
- to determine the optimum lateral load distribution in concrete bridge deck analysis from the past up to the present and advances made and the implications.
- to answer the integrity question using few expansion joints in a simply supported bridge deck,and the use of equal and mix girder spacings in lateral load distribution in bridge deck.

The significance of the study is on the technical knowhow on the analysis of a simply supported concrete bridge deck, and the inter-relationship of structural members in transferring loads.

1.1 Scope of Study

The scope of work are to understand the functions of the structural elements and their inter-relationship in transmitting loads, their internal behaviours in terms of stresses, bending, shear, etc, and the effect of external forces both artificial and natural, so as to produce reliable information, not just approximation, but effective analysis for proper design, detailing, construction, repairs and maintenance culture for a beam and slab bridge deck specifically [1].

1.2 Limitations of study

There are several types of concrete bridgedecks, but, it is only the beam and slab bridge deck type that is discussed in terms of methods of analysis, while the other types of bridge decks such as box girder, prestressing cables etc, and the use of computer software to model load were briefly summarized to reduce volume.

2 MAJOR PHASES IN BRIDGE DECK ANALYSIS

1. Bridge site selection

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2. Intended use of the bridge deck, the shape and the loading arrangement (very important), load analysis and detailed design
3. Method of analysis
4. Operation and maintenance

Concrete bridge configuration is usually made up of:
1. Superstructure (Bridge deck) and 2. Substructure

The project focuses on the bridge deck that is simply supported and the advances or improvement made to reduce the problems associated with several joints in simply supported bride deck.

Bridge decks are considered as part of the highway or railway transportation system and its basic purpose is to satisfy the requirements of the transportation. Bridge decks are analyzed and designed to withstand extreme environmental forces, temperature etc. self weight, imposed loads and transient live loads.

2.1 Bridge Site Selection

Once a suitable bridge site has been selected, the engineer is faced with the problem of making the correct choice of bridge deck. The engineer has a range of bridge deck types and materials from which to select his final solution. The basic analysis problem is the selection of the bridge deck type in terms of structural form and material which provided the most economical solution. The accessibility to the bridge site influences in a way the choice of bridge construction material and method of erection.

2.2 Intended Use of the Bridge Deck, Shape and Arrangement

In order to analyze bridge decks, there is need to understand the intended use of the bridge, the shape and the loading arrangement. It would be noted that the dynamic effect of foot bridge deck and highway bridge deck are not as much as the railway bridge. Once, the intended use of the bridge deck is determined the method of analysis has to be carefully selected either by manual calculations or by the use of computer software.

2.3 Method of Analysis

The choice of the method of analysis of bridgedeck follows after considering the following:

(i) The choice of a bridge deck (ii). The cross-section of bridgedeck. (iii). The loading conditions. (iv). The most economical design. (v). Are there any advantages in the adoption of most economical design. (vi). which analysis of bridgedeck that can be adopted to a particular site. (vii). Appearance (viii). Method of construction and capable contractor (ix). Materials availability.
(x). Drainage. (xi). Maintenance requirement. (xii). Availability and lifting capacities. (xiii). Precast unit or cast in-situ. (xiv). Accessibility to site, mode of transportation and distance.

2.4 Operation and Maintenance

In analysis of bridge deck, safety is of paramount importance compared to construction cost. Also the maintenance cost, the method of construction, the type of loadings, the structural configuration are all interwoven for best method of analysis.

The effect of bearings, expansion joints and stiffness of structural elements are critical in the method of bridge deck analysis. The loading arrangements for worse effects on structural members need to be carefully considered, the load combinations and factor of safety also apply.

If a bridge deck becomes unfit for its purpose during its design life, it makes that particular section of the transport system unserviceable leading to diversions, fall in the capacity utilization of the network and expensive assessment and repair or replacement of the bridge. All these are as results of ineffectiveness in the method of analysis followed by design, construction method and construction supervision.

2.5 Types of Concrete Bridge Deck

Bridge deck can be classified into four categories, namely:- 1. The solid and voided slab (economic for less than 10m span), maximum depth 800mm. 2.The beam and slab (economic for less than 40m span). The box girder bridges (economic for greater than 40m span)

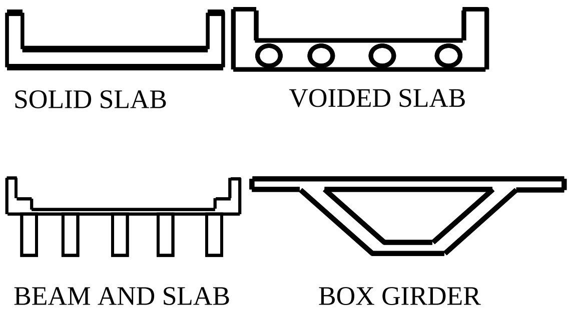

FIGURE 1.1: TYPES OF BRIDGE DECK

2.6 Loading of Bridgedecks

BS 5400: Part 1-14, 1983, [2] to [9]

Loads to be considered are:

1. Self weight of structures (Dead Load)
2. Superimposed dead load (surfacing, kerbs, etc)

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3. Longitudinal breaking/traction force
4. Impact load. 5. Wind load 6. Temperature
7. Shrinkage and creep

Different types of code determine the load on bridge structures e.g BritishCodes (BS), European Codes (Euro Codes), American Codes. BS is generally accepted in Nigeria as majority of Nigerians are trained by British. Only vehicular loads and factor of safety would be briefly mentioned here, other loads could be found in BS5400 and British Design Manual Code, BD37/88, [9]. In **BS5400** the following loads are considered:-

Permanent loads:

British Design Manual Code (BD/01):Part 14; Vol.1, section 3, 1990. [9]

These are defined as **Dead Loads(cl 3.2.2)** from the self weight of the structural elements and **Superimposed Dead Loads(cl. 3.2.3)** from all other materials such as road surfacing, water proofing, parapets, services, kerbs, e.t.c. Also included are loads due to imposed deformations such as shrinkage and creep.

Transient loads(cl 4.3.2):

British Design Manual Code (BD/01):Part 14; Vol.1, section 3, 1990. [9]

These are all loads other than permanent loads and are of short duration, such as traffic, pedestrian, temperature, wind loads and erection loads. Traffic load is divided into two parts. The normal traffic load **(HA)** and abnormal traffic load **(HB).** In the case of railway live loads, **RU** is general railway loading for both goods and passenger, while **RL** is rapid transit passenger and light engineer work trains.

<u>Highway Vertical Live Load</u>

a.) vertical load:

Clause 6.2.1 (i) HA- Uniform loading = $336\ (1/L)^{0.67}$

L=bridge length under consideration

For L=20m, HA (Udl) = $336\ (1/20)^{0.67}$

= 45.1kN/m/notional lane

Clause 6.2.2 (ii) HB: 1 unit of axle load = 10kN

45 unit of axle load = 450kN

$\therefore$1 wheel load $= \frac{450}{4} = 112.5$kN

Factor of safety for material = 1.15

Factor of safety for loads:

Dead load (DL) = 1.15

Superimposed dead load (SDL) = 1.75

Live load (LL) for HB + HA loads = 1.3

Live load (LL) for HA load alone = 1.5

Live load (LL) for footway = 1.5

Load combination must be carefully selected based on code of practice and the worse effect in analysis is considered in design as shown in fig 1.2: Deck Load and Arrangement (Page 12).

2.7 Factors Affecting the Structural Form of Concrete Bridge Deck

Bridge decks are frequently supported on bearings which transmit the loads to the abutments at the bridge deck ends or to piers or walls elsewhere [10]. Joints may be present to facilitate expansion or contraction of the deck at the ends or in the interior.

Joints, however, have their disadvantages on bridge decks as follows:- 1. Maintenance of expansion joints due to wears and tears, and also blockage of openings of the joints.

2. Non smooth ride surface of deck at joints.
3. Non durability of bridge often associated with joints that are leaking which contaminate bearings or substructures with chloride contaminated water.
4. On the other hand, the durability of post tensioned concrete bridges in which inadequate grouting of the ducts can lead to corrosion of the tendons.
5. Bridge decks that were easy to design are usually simply supported spans but problems of leakages at joints and also bearings which require replacement many times over the lifetime of bridge. The advances, improvement or new development is use of few joints and bearings in bridge deck analysis.
6. Method of construction influences the distribution of moment and force in bridge. Use of precast concrete and insitu concrete must be carefully selected to avoid failure at point of meeting in terms of shear, punching, cracks, relative deflection, slippery as a result of poor bond (inadequacy of reinforcement or rough surface) etc., hence, analysis must be carefully carried out.

2.8 Types of Bridge Decks and Advances (Improvement)

Different types of deck are as follows:

a) Beam and slab deck. b) Box girder deck.

c) Incremental launch deck. d) Drop in span.

e) Integral bridge (deck monolithic with abutments and piers).F) Cable stayed bridge. g) Suspension bridge.

It should be noted that these types of decks can be combined to reduced cost depending on the condition of soil supporting piers and abutment and the profile of the bridge.

a) Beam and Slab Deck Structural Form

These are series of simply supported beams and slab on short span deck that is less than or equal to 40m. Different structural forms are as follows :-

1. **Each span with bearing and expansion joint (conventional).** The bridge deck is simple to analysis, design and construct.

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The major disadvantage is too many joints and bearings that are no longer favoured in practice. Maximum moment is very high and most expensive in construction [10].As shown in fig. 1.3: Simply Supported Beam and Slab Convention (page 12).

2.9 Advances (Improvement) On Simple Supported Concrete Bridge Deck

Different structural forms are as follows:

1. Each precast beam with bearings at each ends and slab continuous at supports.

This Bridge deck is simple and little bit tedious in analyses. It has advantage over the first case because the expansion joints have been eliminated. The reduction in maximum moment of beam and construction cost is negligible compared to span with expansion. The continuous slab has low structural stiffness and attracts low bending moment. There is a great concern among some designers about the integrity of this type of joints as it must undergo significant rotation during the service life of the bridge [10]. *The analysis requires that the slab stiffness and length must be carefully selected to get reasonable percentage of reinforcement, as too much reinforcement may not indicate crack before collapse.*See fig. 1.4: Simply Supported Beam and Slab with Continuous Slab at support. (Page 13)

2. Projection of Pier or Pier cap at support and continuous slab at support

The continuous slab at the support is supported underside by providing projected pier or pier cap shooting up to provide superstition support to the slab, thus making it more reliable but increases the cost of construction; but extra cost is justifiable when compared to continuous replacement of expansion joints during the service life of the deck. See fig 1.5: Simply Supported Beam and Slab with Continuous Slab on projected pier (elimination of joint), (page 13)

3. Precast beams and slab continuous over intermediate support with bearings

The bridge deck is simple to analyze and construct. Precast concrete or steel beams are placed initially in a series of simply supported spans. In-situ concrete is then used to make the finished bridge deck continuous over intermediate support. The in-situ concrete makes the beams continuous and also acts as diaphragm (cross beam). *The only problem in the analysis is the inaccurate prediction of creep effect when precast beam is continuous with insitu concrete*. However, experienced engineer will introduce a reduction factor to hogging moment for creep effect. See fig 1.6: Beam and Slab continuous over sliding bearings (page 13)

2.10 Lateral Load Distribution in Bridge Deck

Economy in bridge deck analysis and design can be achieved if the lateral load distribution characteristics can be accurately predicted [1], [11].

It has been found that ten (10) number girders (precast beam) is the number required for effective lateral load distribution for any bridge deck, any additional beyond ten (10) does not exist in lateral load distribution.

Optimum spacing of girders in bridge deck is obtained if girder is spaced at the width of one traffic lane, although bridge profile and other reasons come to play when selecting number of longitudinal deck girders (precast beam) as the efficiency of lateral distribution which depends on the number of the longitudinal girders, increasing with increase in the number of girders.

2.11 Studies of Interconnected Bridge Deck

Deck load distribution studies by Leonhardts and Makowski have led to the following conclusions about Grid Deck Bridges:

1. Except for reinforced concrete grid, a cross-girder is most effective when placed at mid-span of the bridge.
2. In reinforced concrete grillage, in which the torsional rigidity is more important, the effect of the position of the cross-girder is less pronounced, especially if there are several girders.
3. There is no improvement in the lateral load distribution, if more than 5 cross girders are used. It is considered by many bridge designers to be good practice, to have an odd number of cross girders, usually 1 or 3 for small span bridges and not more than 5 for large span bridges.
4. In steel bridges, because of the very low torsional rigidity of the cross girders, the influence of torsion rarely changes the stresses by more than a few % and the joints (even if they are welded) will behave as virtual hinges transmitting only forces and no moment.
5. The efficiency of lateral distribution depends on the number of the longitudinal girder.
6. It has been found that 10 number longitudinal girders is the maximum number required for effective lateral load distribution for any bridge deck, any additional girder beyond 10 does not assist in lateral load distribution.
7. Optimum spacing of girders in girder deck bridges is obtained if the girder is spaced at the width of one traffic lane.
8. Studies have shown that the middle third girders in a bridge deck carry comparatively less loads than the outer third girders [1]. Even when the HB vehicle is placed to produce maximum effect on the middle

ISSN 2320-9186

third girders, that maximum loading is less than that produced on the outer thirds girders with the HB vehicle placed on the outer lane. This deck behavior could be utilized to great economic advantage in deck design by adopting mixed spacing for the girders in such a manner that the total maximum bending moment (i.e. Dead Loading bending moment, superimposed dead load bending moment and Live load bending moment) on the outer third girder is roughly equal to the maximum total bending moment on the middle third girder. The new Kaduna River Bridge would be used to illustrate the point.

3 METHOD OF BRIDGEDECK ANALYSIS

Different methods have been developed to solve this problem, namely;

1. Orthotropic plate theory (Guyon Massonnet-Bares) [12]
2. Orthotropic plate theory (Design Curves) Morris and Little. 3. Simple Grillage. 4. Simple Analysis (Moment distribution and influence line method)
5. Finite element.6. Finite strip. 7. Space frame. 8. Finite difference

Two common methods are explained in the analysis of a simply supported bridgedeck. These are

(i) Guyon-Massonnet Bares Method
(ii) Simplified Grillage Method

Guyon-Massonnet-Bares Method

The objective of load distribution is to assess the magnitude of the load sustained by each longitudinal member of the bridge deck and the extent to which the transverse members assist in distributing the load to the longitudinal members. The two extreme in terms of efficiency is represented by an isotropic slab (having the same elastic properties in all directions) and no torsion grillage. For no torsion grillage, load distribution is effected by Shear resistance at the joints. Slab distributes load by shear and torsion and this represent the optimum with regards to load distribution. In practice, reinforced concrete and prestressed decks will be between these two extremes [12].

Plate analysis of bridge deck has been carried out by the following:

1914 – Huber –R C slabs
1946 – Guyon – Torsionless deck
1950 – Massonet – torsion considered with tables for estimating load distribution coefficients.
1952 – Rowe - Practical application with 10% increase in Massonet results to take into account of poission's ratio.
1974 – Cusens – Extended application of Rowe by providing torsional moment coefficients in form of design curves.

The Plate Equation:

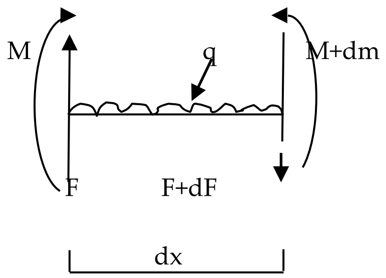


Fig 3.01: Plate Equation

The orthotropic plate equation forms the basis of the Guyon-Massonnet-Bares method of assessing the maximum longitudinal and transverse bending moments in bridge decks using coefficient of lateral distribution.

Considering the equation of a simple beam Fig (3.01), for the algebraic sum of vertical forces

$qdx + (F + dF) – F = 0$

$\therefore\ qdx + dF = 0$

$\frac{dF}{dx} = -q$

For the algebraic sum of moments to be zero and ignoring second order terms

$M - (M + dM) + Fdx = 0$

$Fdx - dM = 0$

$\frac{dM}{dx} = F$

Differentiating w.r.t. x

$\frac{d^2M}{dx^2} = \frac{dF}{dx} = -q$

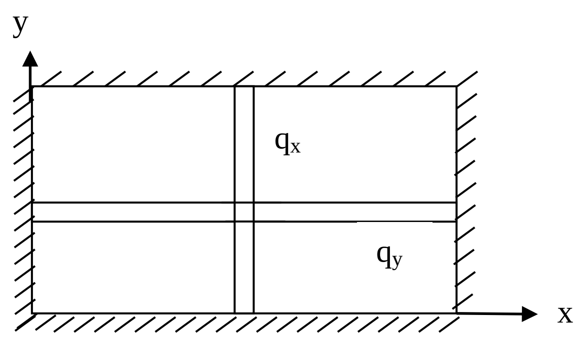
But $M = EI\frac{d^2W}{dx^2}$

Where W = deflection of the beam

$\therefore \frac{d^2M}{dx^2} = EI\frac{d^4W}{dx^4} = -q$

$$EI\frac{d^4W}{dx^4} = -q \qquad (3.01)$$

In order to visualize the behavior of a plate influence, it is convenient to consider it in terms of two sets of beam strips (Fig (3.02).



For the a

Fig 3.02: Plate Equation on X and Y Direction

$q = q_x + q_{xy}$

Substituting for q in (3.01) we have:

$$\therefore \frac{d^4W}{dx^4} + \frac{d^4W}{dy^4} = -(q_x + q_y)\frac{I}{EI} \qquad (3.02)$$

ISSN 2320-9186

If poisons ratio is taken into account then EI is replaced by D where

$D = \frac{Et^3}{12(1-v^2)}$ where t = plate thickness and

v = poisons ratio (approx 0.15 for concrete)

For $1 - v^2 \simeq 1$

The equation of equilibrium of an element of slab to bending moment and twisting moment (Refs. Timoshenko S., Woinowsky -Kriegger S., 1987-Theory of Plates and Shells (page 81) and [13], [14], [15] and [16] is:

$$\frac{d^2M_x}{dx^2} + \frac{d^2M_y}{dy^2} - \frac{2d^2M_{xy}}{dxdy} = -q\ (x,y) \qquad (3.03)$$

It can be written in the form

$$\frac{d^4W}{dx^4} + \frac{2d^4W}{dx^2dy^2} + \frac{d^4W}{dy^4} = \frac{q}{D} \qquad (3.04)$$

where, w = deflection

In equation (3.03) the first two terms represent ideal beam strip action and the third involving twist is:

$$\frac{2d^2M_{xy}}{dxdy}$$

It has been assumed that the elastic properties of the material of the plate are the same in all directions. For the case of orthotropic plate the equation can be written in the form:

$$A\frac{d^4W}{dx^4} + B\frac{d^4W}{dx^2dy^2} + C\frac{d^4W}{dy^4} = q$$

Where A, B, C relate to the flexural and torsional properties of the system.

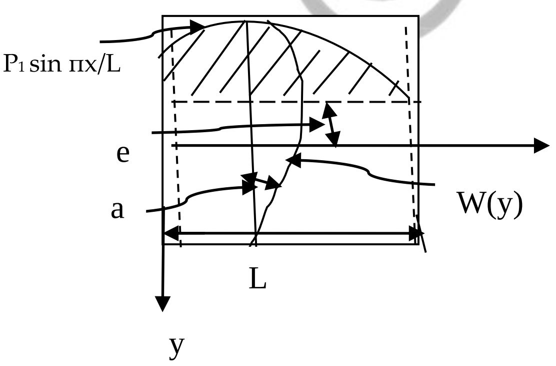


Fig 3.03: Load Line Eccentricity

The system of the simple bridge type as shown in Fig (3.03) is simply supported along the edges X = 0; X = L, and free along the remaining edges y = ±b. The system is acted upon by a sinusoidal line-load in the x-direction. The line along which the load is acting, called the "Load-line" and is parallel to the x-axis at a distance "e" from it, where "e" is the "load eccentricity" due to the line load.

$$P\ (x) = P_1 \mathrm{Sin}\frac{\Pi x}{L} \qquad (3.06)$$

The system deflects to a surface

$$w\ (x,y) = w(y)\ \mathrm{Sin}\frac{\Pi x}{L} \qquad (3.07)$$

The x-direction, is defined again by a sinusoidal law. If the load P(x), as defined by equation (3.06) is distributed over the whole surface width 2b of the system, then the intensity of this load, uniform in the y-direction becomes:

$P_o\ (x) = P_o \mathrm{Sin}\frac{\Pi x}{L}$

Where: $P_o = \frac{PI}{2b}$

Due to this load, the system deflects to a cylindrical surface defined by the equation:

$$W_o\ (x) = W_o \mathrm{Sin}\frac{\Pi x}{L} \qquad (3.08)$$

The ratio of the two deflections, as produced by the line-load P_1 and by the distributed load P_o respectively is called "Principal Coefficient of lateral distribution". Denoting the coefficient by K.

$$K = \frac{w(x,y)}{W_o(x)} = \frac{w(y)}{W_o} \qquad (3.09)$$

The value of the coefficient, k depends on the following factors: a) On the parameter of lateral stiffness (ɵ)

b) On the parameter of torsion (α)

c) On the relative eccentricity of the line-load e/b

d) On the relative ordinate of the considered point y/b

The entire above factor are dimensionless.

The average deflection with respective to a given cross-section of the system is defined by the integral.

$$\frac{1}{2b}\int_{-b}^{+b} w(y)\ dy \qquad (3.10)$$

Dividing both sides by W_o

$$1 = \frac{1}{2b}\int_{-b}^{+b} \frac{w(y)}{W_o}\ dy$$

$$\text{i.e.} \int_{-b}^{-b} w(y)\ dy = 1 \qquad (3.11)$$

Equation (3.11) states that the average ordinate of the influence line of k shall be equal to unity.

Equation (3.10) requires that average ordinate of the influence line of W shall be equal to the value of W_o, i.e. the deflection W_o produced by the load $P_o = \frac{P_1}{2b}$

distributed uniformly over the entire width 2b of the system.

Adopt numerical integration to evaluate equation (3.11) sub-divide the width 2b into 8 equal portions of

ISSN 2320-9186

length 2b/8. This will result in 9 ordinates and the integral can either be evaluated according to Simpson's rule or trapezoidal rule.

Recap: Simpson's Rule:

$\int_s ads = \frac{h}{3}$ (1^{st} + last + 4sum of even + 2xsum of odds)

$h = \frac{2b}{8}$

$\int_{-b}^{b} k(y)dy = \frac{2b}{24}$ [(ko + k8 + 4 (k1 + k3 + k5 + k7) + (k2 + k4 + k6)] (3.12)

Equation (3.12) can be written as:

$$\int_{-b}^{b} k(y)dy = \frac{1}{3}\ [(k_o^{+} + {}^{k}8 + 4\sum k_n + 2\sum km]$$

n = 1,3,5,7 m = 2,4,6

Maxwell's Reciprocal Theorem holds true for distribution coefficients

i.e. k(a,b) = k(b,a)

The coefficient k depends also on the torsional parameter α.

In order to dispense with the necessity of calculating k_α for every particular value of α, Massonnet deduced on the basis of a great number of numerical investigations the interpolation formula

$k_\alpha = k_o + (k_1 - k_o)\sqrt{\alpha}$ (3.14)

Where k_o, k_1 denote the values of k_α relating to α = o and = 1 respectively.

Practical Calculation of k_α is thus based, apart from α, only on the following numerical values.

$K_o = k\left(\alpha = o, \emptyset, \frac{e}{b}, \frac{y}{b}\right)$ and

$K_1 = k\left(\alpha = 1, \emptyset, e/b, \frac{y}{b}\right)$ and

Load Distribution Example

$\Theta = \frac{b}{2a}(i/j)^{1/4} = \frac{b}{2a}\sqrt[4]{i/j} = \frac{b}{2a}\ (i/j)^{0.25}$

Where b = half width of deck

2a = span of deck

i = 2nd Moment of area/unit width

j = 2nd Moment of area/unit length

$\alpha = \frac{G}{2E}\frac{I_o + j_o}{(i\,j)\ ½}$

Where $G = \frac{E}{2(i+v)} \simeq ½E$ = shear modulus

v = poisons ratio

E = modulus of elasticity of concrete

$I_o = \frac{I_o}{P}$ = torsional rigidity/unit width

P = spacing of longitudinal beams

q = spacing of x-girders

Table 1: coefficient of torsional inertia

a/b	ß
1.0	0.141
1.2	0.166
1.5	0.196
1.75	0.213
2.0	0.229
2.25	0.24
2.5	0.249
3.0	0.263
4.0	0.281
5.0	0.291
10.0	0.312
∞	0.333

For I and T sections the torsional inertias of each individual rectangular section are added. Considering a single rectangular section the torsional inertia is given by $\beta\ a(b)^3$

where a> b.

$\alpha = \frac{G(I_o + j_o)}{2E(i\,j)\ ½}$, G ≃ ½E

If the above expression for α is applied to a slab using the thin rectangular section formular, then for a thickness of t,

$\alpha = \frac{\frac{1}{4} x \left(\frac{t^3}{3} + \frac{t^3}{3}\right)}{\left(\frac{t^3}{12} + \frac{t^3}{12}\right)^{1/2}}$

But α varies from 0 to 1.

This anomaly arises from the fact that the overall continuity of the slab in the longitudinal and transverse direction is neglected. The values of i_o and j_o to be used for top slab of beam and slab deck should be halved which gives i_o and j_o equal to $\frac{t^3}{6}$.

It is suggested by Massonnet that the equivalent slab approach is accurate for any grid work of the bridge type providing there are at least three main girders. For any number of intermediate cross girders the assumption of continuously distributed transverse rigidity leads to only very small errors; that only one intermediate girder is sufficient.

Maximum Deck Bending Moment

For the calculated values of Θand α, tables for values of k_o and k_1 are prepared from tables prepared by the Guyon – Massonnet – Bares.

Then, $k = k_o + \sqrt{\alpha}\ (k_1 - k_o)$ based on new k_o and k_1 obtained previously.

The maximum longitudinal moment M_x (total) is calculated based on total load on deck.

The mean longitudinal moment M_x (mean) $= \frac{M_x}{W}$(total)

Maximum deck bending moment (M_x)

M_x =1.1 M_x (mean) x W_1k

W = 2b = width of deck slab

w_1 = width of slab for T-beam under consideration

k= coefficient of reference station considered

1.1= 10% increase to allow for poison's ratio.

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Experimental Programme

To reduce the volume for the concrete bridgedeck analysis,**the Guyon-Massonnet-Bares Method**is used.

The Guyon-Massonnet-Bares Method

The Guyon-Massonnet Method is the method employed, which uses the approach of orthographic plate analysis, for load distribution analysis of bridge decks.

The main objective of a load distribution analysis is to assess how much of the HB load is sustained by each of the longitudinal members of the bridge deck and the extent to which the transverse members assist in distributing the load to the longitudinal members.

Analysis Procedure

The procedure is very long and requires many pages, so it can only be summarized .

i) Determine the flexural and torsional parameters of the bridge deck.

For deck span, L = 2a

For deck width, W = 2b

Adopting the load combination analysis of worse severe effect.

General Lane Arrangement

The number of lanes needed for the analysis of this bridge deck is determined as [3] to [9]

Adopt equal spacing of beams

$S = \frac{11}{5} = 2.20$

Use a spacing of **2.250m** and end cantilevers of **1.000m**

Lane width = **2.25m**

General Data on Bridge Deck

Following the selection of bridge deck structure (bridge deck type), in terms of structural form, the materials, and the loading condition the underlisted data are used in the bridge deck analysis.

British Design Manual Code (BD 37/88) Vol.1. Part 14. Loads for Highway Bridges. 2) BS 5400, part 4, 1990. 3) BS 8110, part 1, 1997 [3], [9].

Bridge spans: 20.00m

Carriageway width:	11.00m
Loadings:	HA + 45 units of HB
Surfacing:	0.05m

Load Cases Considered in Analysis

Case 1:	Dead load
Case 2:	Superimposed Dead load
Case 3:	HA+45 units HB loads
Case 4:	Local effect of wheel load
Case 5:	Temperature Effect
Case 6:	Wind load effect
Case 7:	Braking/Traction load

Deck Loading (Transverse Loading)

HA Loading

Carriageway width = 8.0m

Width of lane $= \frac{8.0}{3(\text{No.of notional lanes see table 2})}$

= 2.67m (lane width)

Bridge deck length, L= 20 m

HA loading is made of:

a) vertical load:

Clause 6.2.1 (i) HA- Uniform loading $= 336\,(1/L)^{0.67}$

$= 336\,(1/20)^{0.67}$

= 45.1kN/m/notional lane

HA Udl across notional lane = 45.1kN/2.67

$= 16.89\text{kN/m}^2$

b) KEL = 120kN/m = 120kN/m/2.67 = 44.94 kN/m^2

c) Clause 6.2.2 HB: 1 unit of axle load = 10kN

45 unit of axle load = 450kN

$\therefore$ 1 wheel load = 450/4 = 112.5kN

Adopt static distribution to transfer loads to the girders comprising the girder spacing and the lane width, it can be seen that a girder carries a lane load.

Table 2:Number of notional lanes BS 5400 (Part 14: British Standard Code (BD37/01), 1990 [3], [9]

Carriageway width	Number of notional lanes
5,000 up to and including 7.50	2
Above 7.50 up to and including 10.95	3
Above 10.95 up to and including 14.60	4
Above 14.60 up to and including 18.25	5
Above 18.25 up to and including 21.90	6

Material Properties:

Precast Concrete Beam

Cube strength at 28 days $U_w = 52.5\text{N/mm}^2$

Cube strength at 28 days $U_t = 52.5\text{N/mm}^2$

Maximum permissible stress[17]

	comp	tension
At transfer of prestress	$U_t/2$	- 1.00 N/mm^2
Under working load	$U_w/3$	0

In-Situ Concrete Slab

Cube strength at 28 days, $U_w = 30.0\text{N/mm}^2$

Minimum permissible stress:

	comp	tension
Under working load,	$U_w/3$	no limit

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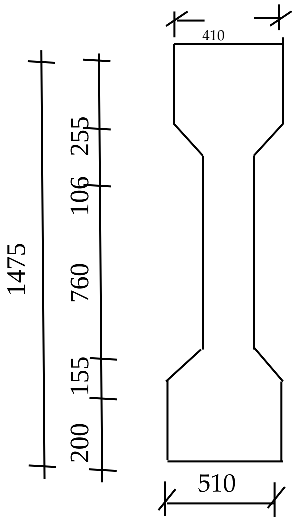
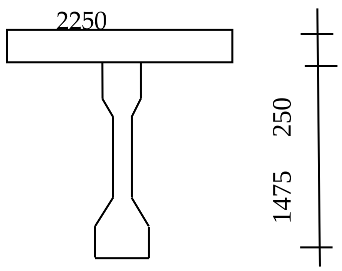
Section Properties
Flexural Properties
Precast Beam



Depth of beam = 1475
Area of beam = $445.6 \times 10^3 mm^2$
Height of centroid above
Soffit y_b = 707mm
Second moment of area
$I_p = 106607 \times 10^6 mm^4$
Radius of gyration
r = 489mm
Section moduli
Top fibre, $Z_t = 138.81 \times 10^6 mm^3$
Bot. fibre, $Z_b = 150.79 \times 10^6 mm^4$

Composite Section



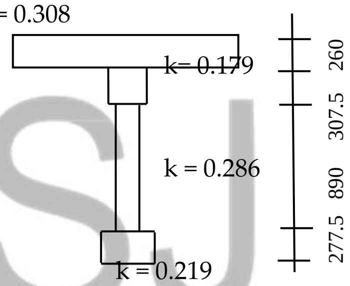
Modular ratio, m = $\sqrt{30/525} = 0.76$
Total depth = 250 + 1475 = 1725mm
Equivalent area of slab = 0.76x250x 2250 = $427500mm^2$
Area of precast section = $445600mm^2$
Height of centroid above soffit
$y_b = \frac{427500 \times 1600 + 445600 \times 707}{427500 + 445600} = 1144.24mm$
Second moment of area
$I_c = (0.76 \times 2250 \times 250^3)/12 + 427500\,(1600 - 1144.24)^2 + 106607 \times 10^6 + 445600\,(1144.24 - 707)^2$
$= 307.31 \times 10^9 mm^4$

Section moduli
Bottom of precast, $Z_b = \frac{307.31 \times 10^9}{1144.24} = 268.37 \times 10^6 mm^3$
Top of precast, $Z_t = \frac{307.31 \times 10^9}{330.76} = 929.12 \times 10^6 mm^3$
Top of insitu, $Z_{t\ insitu} = \frac{307.31 \times 10^9}{580.76} = 529.16 \times 10^6 mm^3$

Transverse In-Situ Top Slab
Second moment of area
$I = 1/12 \times 1000 \times 250^3$
$= 1302.08 \times 10^6 mm^4$/mlength of slab

Torsional Properties
The torsional rigidities are found by considering the individual rectangles and adding these with the proviso that for rectangles representing 2-way continuous sections only half the torsional rigidity is used.
$\eta = kc^3d$ where $c \leq d$

Longitudinal Direction
Torsional inertia in the longitudinal direction is calculated using the idealized section below



$GI_o = 1/2G \times 0.308 \times 250^3 \times 2250 + 0.179 \times 307.5^3 \times 410G$
$= 0.286 \times 200^3 \times 890G + 0.219 \times 277.5^3 \times 510G$
$= (5414.06 + 2133.89 + 2036.32 + 2386.33) \times 10^6 G$
$= 11971 \times 10^6 G\ mm^4$

:. $G_{io} = \frac{11971 \times 10^6}{2250} = 5.32 \times 10^6 G\ mm^4/m$

Transverse Direction
$G_{io} = \frac{½ \times 0.333 \times 1000 \times 250^3 G}{1000} = 2.602 \times 10^6 G\ mm^4/m$

Flexural And Torsional Parameters
Longitudinal section inertia
$i = \frac{307.31 \times 10^9}{2250} = 136.58 \times 10^6 mm^4/m$ width
In-situ transverse slab inertia
$j = 1/12 \times 1000 \times 250^3 = 1.302 \times 10^6 mm^4/m$
Take effective width of bridge = actual width,
b = 11.0m, Length, a = 20.00m
Hence, $\Theta = \frac{b}{2a}\sqrt[4]{i/j} = 11.0/2 \times 20\sqrt[4]{136.58/1.302}$
=0.88
and $\alpha = \frac{G(i_o + j_o)}{2E\sqrt{(ij)}} = \frac{½ \times 0.435 \times (5.32 + 2.602)}{\sqrt{(136.58 \times 1.302)}} = 0.129$
[G/E = 0.435]

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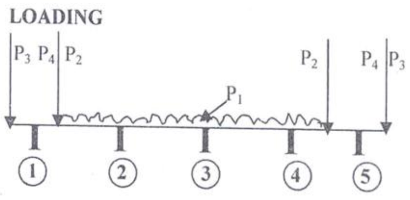


Dead Load

Self weight of beams = 0.4456 x 25 = 11.14KN/m
Deck slab (2), (3)&(4) = 0.25 x2.25 x 25 = 14.06KN/m
(1) & (5 = (1.0 + 0.5 x2.25) x 0.25 x 25 = 13.38KN/m

Superimposed Dead Load

Surfacing (50m thick), P_1 = 0.050 x 24 = 1.20KN/m
Parapet P_2 = 0.25 x 0.30 x 24 = 1.80KN/m
Parapet P_3 = 0.20 x 1.0 x 24 = 4.80KN/m
Railing P_4 = take as = 1.00KN/m

The reactions on the beams are as follows:

$R_{(1)}$ = 4.80 +1.00 +1.80 x $\frac{1.75}{2.25}$ x 1.2 x 1.75 x $\frac{0.875}{2.25}$+ $\frac{6.59}{2.25}$
= 10.95KN/m

$R_{(2)}$ = 0.40 + 1.28 + 1.2 x$\frac{2.25}{2}$- $\frac{6.59}{2.25}$- $\frac{1.97}{2.25}$
= -0.74KN/m

$R_{(3)}$ = 1.20 x 2.25 + 2 x$\frac{1.97}{2.25}$
= 4.45KN/m

$R_{(1)}$ + $R_{(2)}$ + $R_{(3)}$ + $R_{(4)}$ + $R_{(5)}$ = 2 x10.05-2x0.74+4.45
= 24.87KN/m
Total loads = 8x1.20 + 2x1.8x2x4.8+2x1.0
= 24.80KN/m

Live Load

British Design Code (BD 37/01: Part 14: Vol. 1. Section 3, 1990) [9], [18]
KEL = 120KN/m
Clause 6.2.1 (i) HA- Uniform loading
Clause 6.2.2 HB: 1 unit of axle load = 10KN
45 unit of axle load = 450KN
HA udl = 30 x 3/8 = 11.25KN/m
HA kel = 120 x 3/8 = 45.0KN/m
HB 45 units (each axle) = 45 x 10 = 450KN/m (1 unit of each axle load = 10KN)

Maximum Longitudinal Moment
Dead load

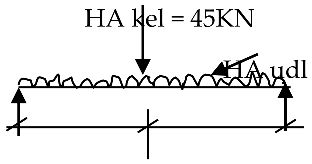
Precast beams Mg_1 =$\frac{11.14 \times 20^2}{8}$= 557.0KN
Deck slab (2), (3) (4), Mg_2=$\frac{14.06 \times 20^2}{8}$= 703.0KN/m
(1) & (5), Mg_3=$\frac{13.38 \times 20^2}{8}$= 669.0KN/m

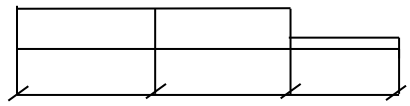
Superimposed Dead Load

Beams (1) & 5, M_P=$\frac{10.95 \times 20^2}{8}$= 547.5KN/m

Beam (2) M_P=$\frac{4.45 \times 20^2}{8}$= 222.5KN/m

Ha Loading





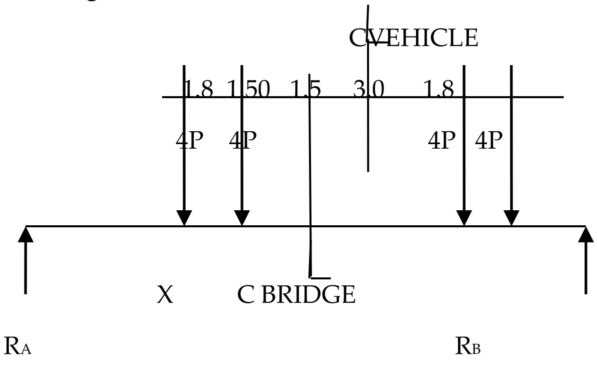
2.67m 2.67m 2.67m

11.25KN/m 11.25KN/m
HA HA 1/3 HA= 3.75KN/m

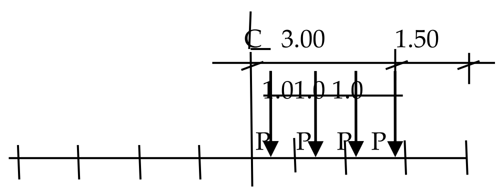
Max gross moment M=20^2/8(11.25x5.33+3.75x2.67)+ ¼ x20 x 45
=3723.75KNm
Average gross moment = 3723.75/8
= 465.47KNm/m
= 465.45 x 2.25 = 1047.26KNm/beam
Full HA average moment = 20^2/8 x 11.25 = 562.5KNm/m
= 1265.63KNm/beam

Hb Loading

Loading Positions



LONGITUDINAL POSITIONS



-b -3b/4 -b/2 -b/4 0 +b/4 +b/2 +3b/4 +b

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TRANSVERSE POSITIONS

R_A = 450/20 (3.70 + 5.50 + 11.50 + 13.30) = 765KN
BM = 765 X 8.50 – 450 x 1.80 = 5692.5KN
Mean moment, Mean = 5692.50/5 = 1138.5KN/beam

Table 3: Equivalent loads ^p at the nine standard positions:

POSITIONS	-b	-3b/4	-b/2	-b/4	0	+b/4	+b/2	+3b/4	+b	∑
λ	0	0	0	0	0.273	1.272	1.364	1.091	0	4

Longitudinal Load Distribution

$\Theta = 0.88$

Table 4: Interpolation between K_0 and K_1 using Guyon-Massonet-Bares chart [12]

Interpolation between K_0 and K_1 to find $K\alpha$,

Where $K_\alpha = K_0 + (K_1 - K_0)\sqrt{\alpha}$
and $\alpha = 0.129$

Table 5: K_α coefficient

	REFERENCE STATION									
K_α	LOAD POSITION	-b	-3b/4	-b/2	-b/4	0	+b/4	+b/2	+3b/4	+b
	0	-0.14	+0.43	+0.2	+1.61	+1.88	+1.61	+1.01	+0.43	-0.14
	+b/4	-0.24	+0.12	+0.55	+1.03	+1.61	+1.90	+1.64	+1.03	+0.38
	+b/2	-0.20	-0.01	+0.21	+0.53	+1.01	+1.59	+2.04	+1.90	+1.59
	+3b/4	-0.07	-1.35	-0.01	+0.13	+0.43	+1.04	+1.89	+2.86	+3.72
	+b	+0.04	-0.08	-0.20	-0.23	-0.14	+0.37	+1.56	+3.72	+0.48

Table 6: Distribution coefficient k' for max longitudinal moment

Table 7: Actual beam position in terms of effective width

BEAM	1	2	3	4	5
	-0.8186	-0.4096	0	+0.4096	+0.8186

Table 8: Distribution coefficients at actual beam positions

BEAM	1	2	3	4	5
	-0.27	-0.13	+1.10	+1.71	+1.76

REFERENCE STATION										
LOAD POSITION	**EQUILOAD COEFF (λ)**	-b	-3b/4	-b/2	-b/4	0	+b/4	+b/2	+3b/4	+b
0	0.273	-0.04	+0.12	+0.28	+0.44	+0.51	+0.44	+0.28	+0.12	-0.04
+b/4	1.272	-0.31	+0.15	+0.70	+1.31	+2.05	+2.42	+2.09	+1.31	+0.48
+b/2	1.364	-0.27	-0.01	+0.29	+0.72	+1.38	+2.17	+2.78	+2.59	+2.17
+3b/4	1.091	-0.08	-1.47	-0.01	+0.14	+0.47	+1.13	+2.06	+3.12	+4.06
$\sum\lambda K_\alpha$		-0.70	-1.21	+1.26	+2.61	+4.41	+6.16	+7.21	+7.14	+6.67
$K = \sum\lambda K_\alpha/4$		-0.18	-0.30	+0.32	+0.65	+1.10	+1.54	+1.80	+1.79	+1.67

Maximum moment (Beam 5) $= 1.1 \times M_{mean} \times 1.76$
$= 1.1 \times 1138.5 \times 1.76$
$= 2206.34$ KNm

LOCAL EFFECT OF WHEEL LOAD

Using Professor H.M. Westargaard's Method, 1990
Thickness of surfacing = 50mm
Principal moment due to wheel load P_1 at mid span of slab

$$M_{ox} = \frac{P_1.S}{(2.32 \times S + 8c)}$$

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Where P_1 = 112.5KN

c = effective diameter of loaded area x 2 thickness of surfacing = (190 +100)

S = spacing of beams =2250mm

$M_{ox} = \frac{2250P_1}{2320 \times 2250 + 8(190+100)}$

= 0.2984 P_1

= 0.2984 x 112.5 = 33.57 KNm/m

$M_{oy} = M_{ox} - 0.0676\, P_1$

= 33.57 – 0.0676 x 112.5

= 25.9KNm/m

Due to continuity in transverse direction of slab over beam (effects of encastring the support), the Principal moments become:

$M'_{ox} = M_{ox} - 0.0699P_1$

= 33.57 - 0.0699 x 112.5

= 25.71KNm/m

$M'_{oy} = M_{ox} - 0.1063P_1$

= 33.57 – 0.1063 x 112.5

= 21.61KNm/m

Moments

Support : M = 19.84 + 8.93 = 28.77KNm/m

Span : M = 40.77 + 1.94 = 68.0KNm/m

Dist. : M = (longitudinal design moment)

= 1.30 x 21.61

= 28.09KNm/m

Reinforcement

British Standard BS 8110 – 1997, [17], [19],[20], [21]

$A_s = M/2fy$

Main reinft. Limit: A_s min. = 0.25% A_{smax} = 4%

f_{cu} = 30 N/mm^2 f_y = 410 N/mm^2

h = 250mm b = 1000mm;

Ø = 16mm

Support $A_s = \frac{28.77 \times 10^6}{0.85 \times 215 \times 1.25 \times 220}$

= 572mm^2/m, (provide Y16-175(T))

Span $A_s = \frac{68.01 \times 10^6}{0.85 \times 190 \times 1.25 \times 220}$

= 1531mm^2/m, (provide Y20-175(15))

Dist. $A_s = \frac{28.09 \times 10^6}{0.85 \times 174 \times 1.25 \times 220}$

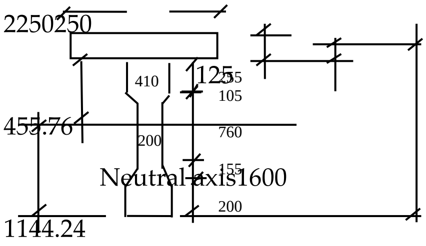
= 691mm^2/m, (provideY12-150(T&B)

Note

1) Bottom reinforcement to be placed on top of precast plank which acts as cover
2) Cover for top steel = 25mm

Temperature EFFECT

(BS 5400: PART 14; 1990, British Design code (BD 37/01):Vol.1 section 3), [3]



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Sectional properties

<u>Beam section</u>

Depth of beam = 147mm

Area of beam = 445600mm^2

Height of centroid of beam above soffit, y_b = 707mm

Second of moment of area, I_p = 106607 x 10^{6}mm^4

Radius of gyration, r = 489mm

= 250mm

<u>Composite Section</u>

Total Depth of beam + slab = 1475 + 250 = 1725mm

Equivalent of area of slab = 0.76x250x2250

= 427500mm^2

Area of precast section (Beam) = 445600mm^2

Height of centroid above soffit, y_b = (slab + beam)

= 1144.24mm

Second of moment of area, I_c = 307.31 x 10^{4}mm^4

Moment due to temperature effect;

M = ƐAEd

Using the relevant code for concrete slab, groups 3 & 4;

Ɛ = 100 x 10^{-6}/^{o}c

E = 26 x 10^{6}N/mm^2

d = distance between centroid of concrete slab and neutral axis of composite section

= 455.76mm

:. M = 100 x 10^{-6} x .5625 x 26 x 10^6 x 0.45576

= 666.55KN/m

Wind Load Effect

(BS 5400: PART 14; 1990,British Design Code BD 37/01:Vol.1 section 3), [9]

Site hourly mean wind speed

$V_s = V_b S_p S_d S_a$

Where V_b = Basic hourly mean wind speed

S_p = Probability factor

S_d = Direction/speed factor

S_d = Altitude factor

V_s = 35 x 1.00 x 1.00x 1.6 = 56.00m/s

<u>Dynamic pressure:</u>

q = 0.613 V^2_c

= 0.613 x 56

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= 1.92 KN/m^2

Transverse wind load:

P_t = qAC$_D$

A = side area of parapet beam and slab x 20m

= (1.00 + 1.475 + 0.25) x 20 = 54.5m^2

Ratio of deck width and depth = 11.0/2.725 = 4.04

From relevant BS Code, chart, C_D = drag coeff. =1.4

:. P_t = 1.92 x 54.5 x 1.4 = 146.5KN

Design = 1.6.50 x 1.5 = 219.75KN

Moment due to P_t:

M = F.d = P_t.d = 219.75 x 0.45576

= 100.15KNm

Longitudinal wind load

(i) Nominal longitudinal wind load or superstructure (Bridge deck)

P_{LS} = 0.25 qAC$_D$

= 0.25 x 1.92 x 54.5 x 1.4

= 36.624 KN

(ii) Nominal longitudinal wind load on the live load (ie. Load on 2.5m high vehicle)

P_{LL} = 0.5 qAC$_D$

= 0.5 x 1.92 x (2.5 x 20) x 1.45

= 69.6 KN

Total longitudinal wind load = 36.624+69.6 =106.22 KN

Design = 106.22 x 1.5 = 159.33 KN

Moment due to P_{LL} + P_{LS};

M = F.d = (P_{LL} + P_{LS}) x d

= 159.33 x 0.45576

= 72.62 KNm

Breaking/Traction Force

BS 5400 Parts 1-9, 1990, Vol.1 section 3

From relevant BS Code; [3] to [9]

HA = 8.00 x15.0 + 200 = 320 KN< 700KN

HB = 0.25 x 4 x 450 = 450KN < 700KN

Use higher value between HA and HB

Adopt 450 KN

Design = 450 x 1.5 = 675 KN

Moment due to Breaking/Traction Force:

M = F.d

= 675 x 0.45576

= 307.64 KNm

Check For Deflection

Self weight of beam = 0.4456 x 25 = 11.14KN/m

Self weight of slab (max.) = 0.25x2.25x25 = 14.06KN/m

= 25.20KN/m

Ip (beam) = 106607 x 10^{6}mm^4

Ic (beam + slab) = 307.31 x 10^{9}mm^4

Deflection due to self weight of beam

ɗ = 5/384 x wl^4/EI

= 5/384 x 11.14 x 20^4/28 x 10^6 x 0.106607 = 8mm

Deflection due to beam + slab

ɗ = 5/384 x 25.20 x 20^4/28 x 10^6 x 0.30731 = 6mm

Allowable deflection:

L/250 =20,000/250 = 80mm > 8mm Ok

Pre-camber not required as beam deflection is negligible

Bearing Design

Properties of Glacier Plain Elastrometric[9], [10] Pad Bearing to BS5400 Part 9, 1990

Dimension = 50 x 320 x 12

Permissible vertical load = 817.0KN

Permissible Rotation = 0.00065 rad/100KN

Permissible shear deflection = 8.4mm

(a) <u>Check for vertical load</u>

Max. service vertical load = 765KN

+(Transverse positions, RA=765KN,Pg.9)

:. Max. service vertical load = 765KN < 817.00KN Ok

(b) <u>Check for displacement</u>

Actual displacement:

ɯ = HT/n.A.G

where T = bearing thickness = 12mm

n = No of bearing = 5

A = Area f Pad = 400 x 400 = 0.16m^2

G = Shear Modulus = 0.1KN/cm^2

H = Horizontal forces = 550.18KN

ɯ = 550.18 x 12/5 x 50 x 32 x 0.1 = 8.25 < 8.4mm Ok

(c) **<u>Check for Rotation</u>**<u>(BS 5400, Part 9; 1990), [9],[10]</u>

Rotation due to DL = 0.00025077

Rotation due to SDL = 0.00001287

Rotation due to LL = 0.0007313

Rotation = 0.00099489/765 = 0.0009949

= 0.00013005 rad/100KN

< 0.00065 rad/10KN Ok

Selected bearing is adequate

4 CONCLUSION

In selecting method of analysis for simply supported concrete bridge deck, there is need to understand bridge in terms of aesthetics, planning, loadings, economy, safety, structural theory, flexibility, articulation, modeling, method of construction, restraints conditions, expansion joints, types of foundation, types of substructures, types of superstructures, length and width, environmental factors like hydraulics, soil-structure interaction, collision and seismic (earthquake) as bridge engineer is architect, analyst, designer and contractor.

The method of analysis can be simply using moment distribution, influence line, Influence Surfaces of A. Puncher charts or Westergaard's Method, and complex using Guyon-Massonet-Bare charts, grillage

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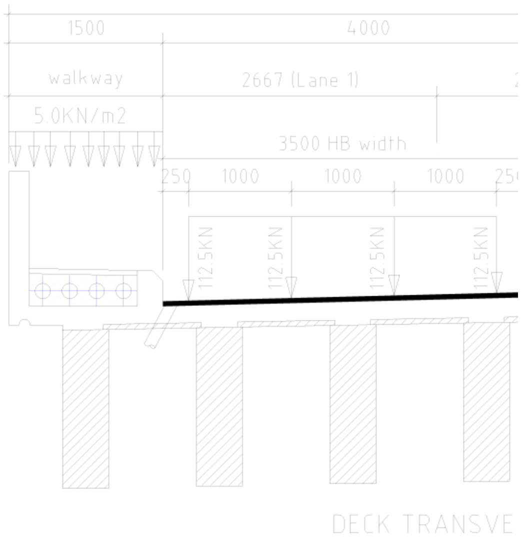
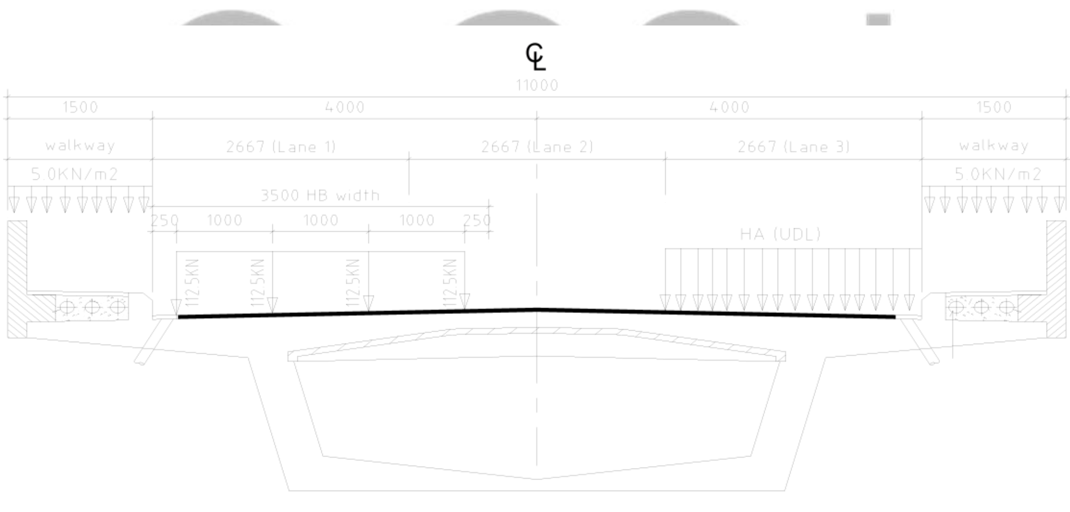
or finite element for Box Girder or Beam and Slab Bridge. The best method is use of computer programme software which has passed through enormous research, fast and user friendly.

Recommendation

The use of computer prog nowadays because of it us reliable results. However, mu

only on how to use computer for concrete bridge deck analysis but to really understand the theory behind it, the basic calculations for input data and interpretation of results for proper design.





BOX GIRDER LOADING ARRANGEMENT
FOR MAX. CANTILEVER MOMENT

ISSN 2320-9186

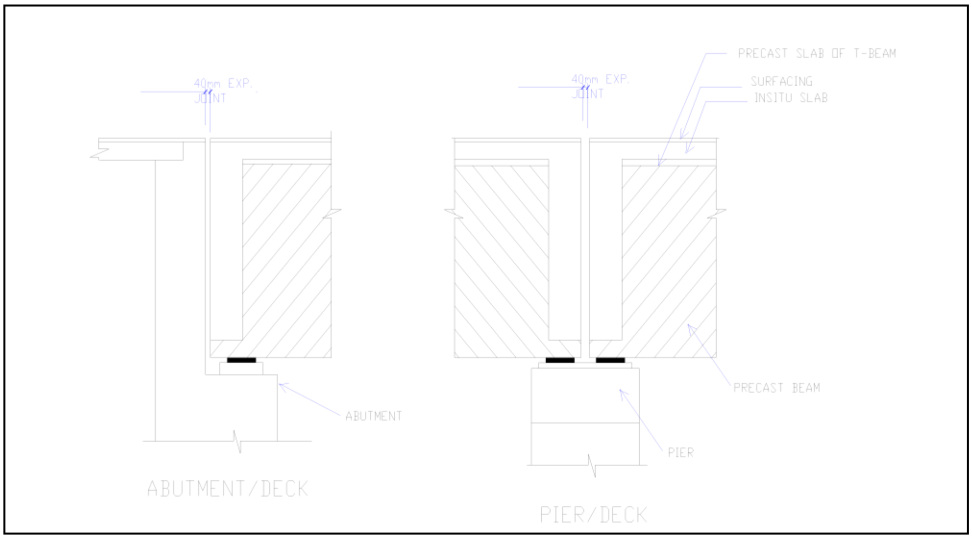


FIGURE 1. 3: Simply Supported Beam And Slab (Conventional)

FIGURE 1.4: Simply Supported Beam And Slab With Continuous Slab At Support (Elimination Of Joint)

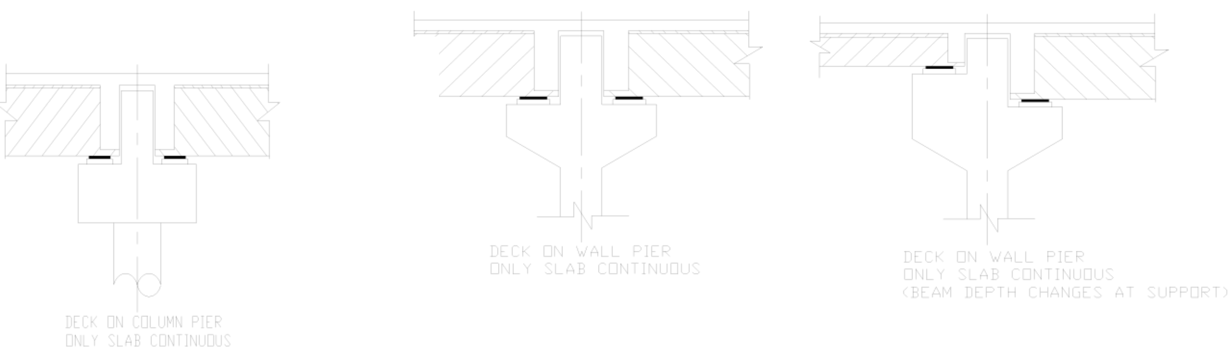


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FIGURE 1.5: Simply Supported Beam With Continuous Slab On Projected Pier (Elimination Of Joints)

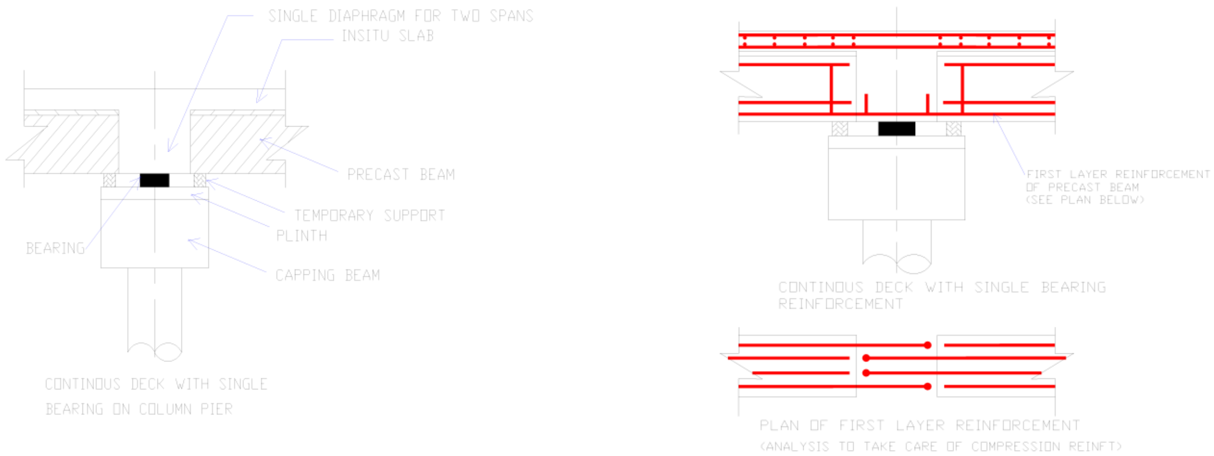

Figure 1.6: Beam And Slab Continuous Over Sliding Bearings

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