A BUILT-UP TIMBER GIRDER FOR BRIDGE CONSTRUCTION IN DEVELOPING COUNTRIES

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Abstract

Just as it is in developed countries, most developing countries utilize concrete and steel in their various forms of reinforced concrete, prestressed concrete and steel, for the construction of bridges. Now, most of these countries do not produce cement and steel locally and have to rely on their importation. As a result, a large proportion of their hard earned foreign currency is utilized for the importation and construction of these bridges. Paradoxically, many of these countries abound in timber as a natural resource which could be utilized for the purpose. The authors have identified the bridge girder as the main constraint in the use of wood for medium span bridges and have developed a built-up timber girder to solve the problem. The paper gives the highlights of the girder for the project, discusses why the girder is appropriate to developing countries with timber as a natural resource and outlines important factors that need to be considered in the design and construction of such a girder.

Keywords: Built-up, timber girder, bridge construction, developing countries, web laminations and flanges.

Introduction

In Ghana, like in many developing countries, cement and steel in their various forms of reinforced concrete, prestressed concrete and steel members, are utilized for bridge construction, even though these materials are to a large extent imported into the country. The cost to the nation for these importations is very great, when one considers the nation's foreign exchange earnings.

Ghana, however, abounds in various species of timber with a broad spectrum of properties, many of which are excellent for bridge construction. It was therefore necessary to consider timber as a substitute for the imported materials, for bridge construction.

In examining why wood had not been considered before this time, reasons identified are:

i. wood easily decays in the tropics in its natural state due to fungal and insect attack. People are prejudiced against the use of it for permanent bridge construction because of this defect.
ii. sawn timber is limited in its length and height and therefore limits bridge spans that wood may be utilized for.
iii. many wooden bridges built previously were built by a rule of thumb and were ugly and served as a short term solution to crossings.
iv. wood is combustible and this makes it vulnerable to bush fire outbreaks during the dry season.

To overcome these disabilities of wood for bridge construction:

i. use is made of naturally durable timber which is further chemically treated using copper chromium arsenate.
ii. a new mechanically built-up girder capable of being designed for a long span bridge has been developed by the authors.
iii. the bridge is designed to be aesthetically pleasing.
iv. by creating firebelts around the bridge using stonework the bridge may be preserved against bush fires.

Highlights of the Girder

The girder consists of two side flanges at the upper and lower ends. In some circumstances, top and bottom flanges may be included (Figure 1). These flanges are mechanically held to web laminations through the use of bolts. The web laminations consist of two layers with the laminations of one layer being diagonal to the other layer's laminations. Theoretically, a bolt is placed at every center of intersection of two diagonal laminations. Timber plates are placed at the extreme ends of the girder to act as:

i. bearing stiffeners.
ii. to connect web laminations which terminate at girder ends.

The advantages of using such a girder for a developing country are many.

i. Long span girders may be easily built using the system of connection as shown in Figure 2. Note that, in a long span bridge only flanges need to be lapped.
ii. It is possible to fabricate such a girder in a workshop under strict supervision, and later transport it to the bridge site to be assembled in position.
iii. Only simple tools are required and hence avoids the use of expensive machines.
iv. It is labor intensive; which is advantageous to a country with a high unemployed labor force.
v. It does not require very highly skilled artisans. Any artisan with experience in handling electric saws, planes and drills, is capable of handling the project.
vi. Bolts utilized for fabrication are easily manufactured from concrete steel reinforcing bars. The durability of the bolt maybe improved through the process of "blueing", in which the bolts are heated to about 400°F and suddenly quenched in residual engine oil.
vii. It avoids the use of steel gusset plates which may be expensive in these countries. This is an added advantage over a timber lattice girder or truss girder.

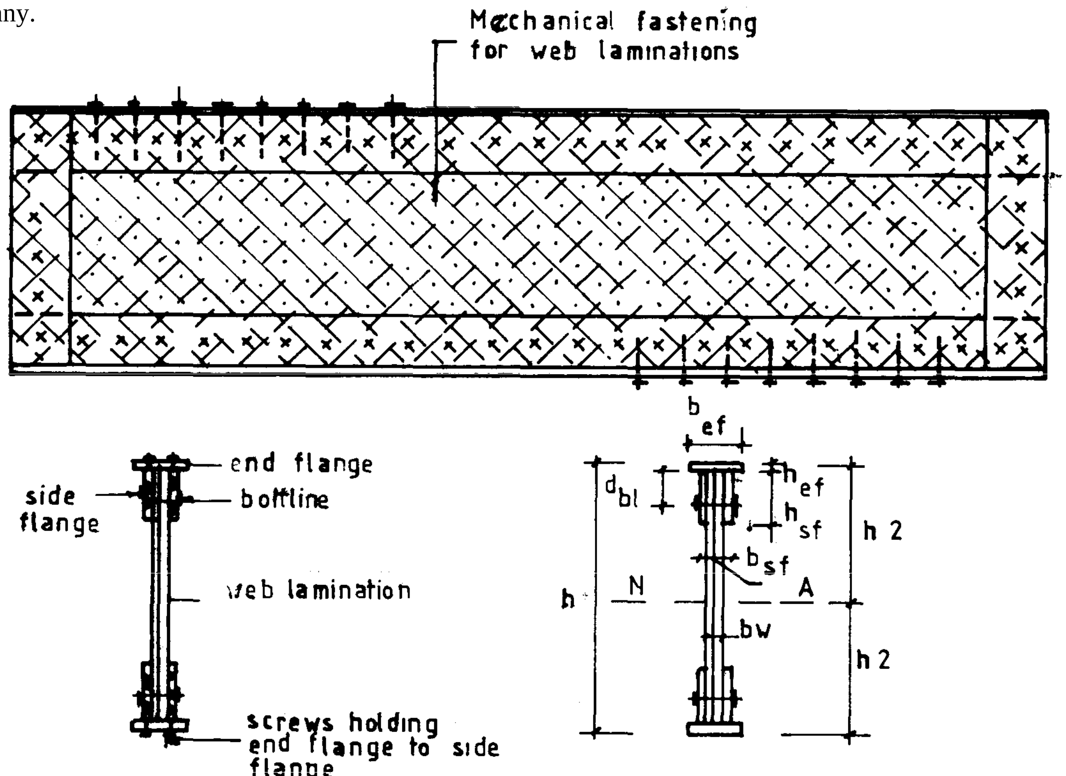

Figure 1 — Mechanically built-up timber girder for the project

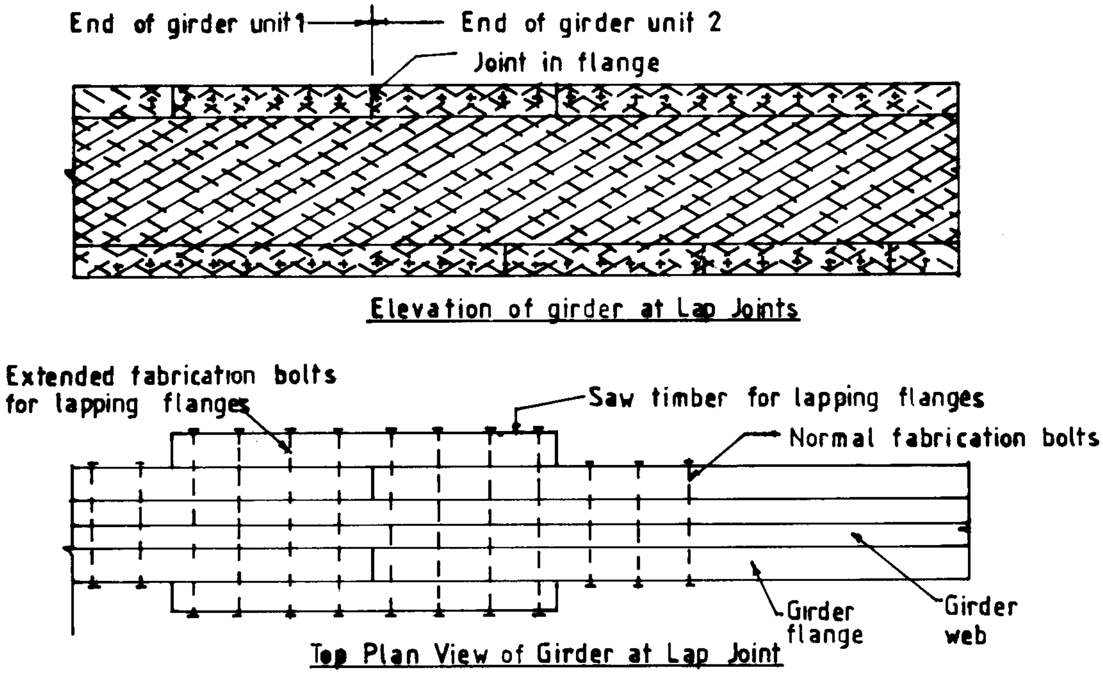

Figure 2 – Moment connection between two girder parts

Geometrical Arrangement of Web Laminations

Geometrical Relationships

For proper fabrication of the girder, it is imperative to arrange the layer laminations in such a way that, the centerline of a lamination in one layer, crosses the centerline of another lamination in the second layer, along a given line within flanges as shown in Figure 3. This line may be referred to as the bolt line.

With this arrangement, if *d is* the distance between the upper and lower bolt lines, is the angle of inclination of web laminations with the axis of the girder and *w* is the width of each web lamination, then, there is a relationship between *d,* and *w,* given as

$$\frac{n}{\cos\mu} = \frac{d}{(w/2)} \qquad (1)$$

where *n* is an integral number, giving the number of web laminations lying within the two laminations discussed above. This is easily verified from the diagram and implies that once any three of the above variables are chosen, the fourth variable is fixed.

In design, one may assume *d* and *w;* then *n/cos* is known. It may also be desirable to have close to a given angle say 30°. The value of *n* may then be computed which would most likely be a non-integer. An integer number above or below the value obtained for *n* may then be assumed and reevaluated, the value of which will be close to 30°.

Common Point of Origin to Draw Web Laminations

Referring to Figure 4, if O is the geometrical center of the girder, and the centerline of lamination 1 is drawn through O, then the position of lamination 2 centerline is fixed. It easy to see that if *n* is an even integer, then one other lamination, (3), parallel to (2), will pass through O, since *n/2* is an integer. Hence, to start drawing laminations, one may start from O.

However, if *n* is an odd integer, then *n/2* is a non-integer and a common point O from which the other lamination may be drawn moves from O along lamination 1 to a point O such that the vertical distance of O' from O, h_{vert}, is given by the relationship (Figure 4).

$$h_{vert} = \frac{w}{4\cos\mu} \qquad (2)$$

Adherence to these geometrical equations will produce a mirror image arrangement of web laminations for the two layers.

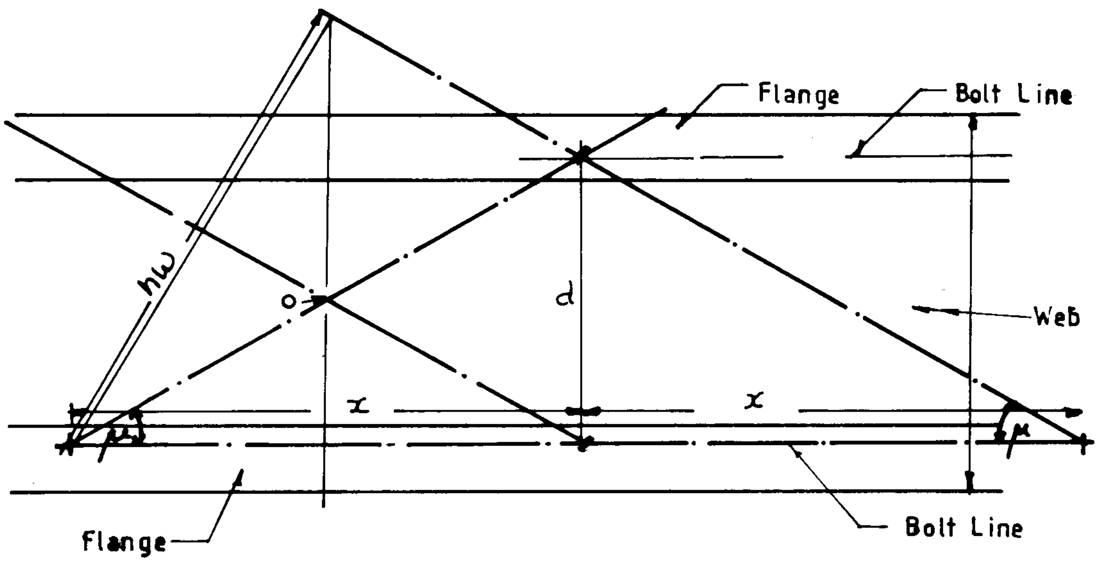

Figure 3 – Geometrical relationships in girder

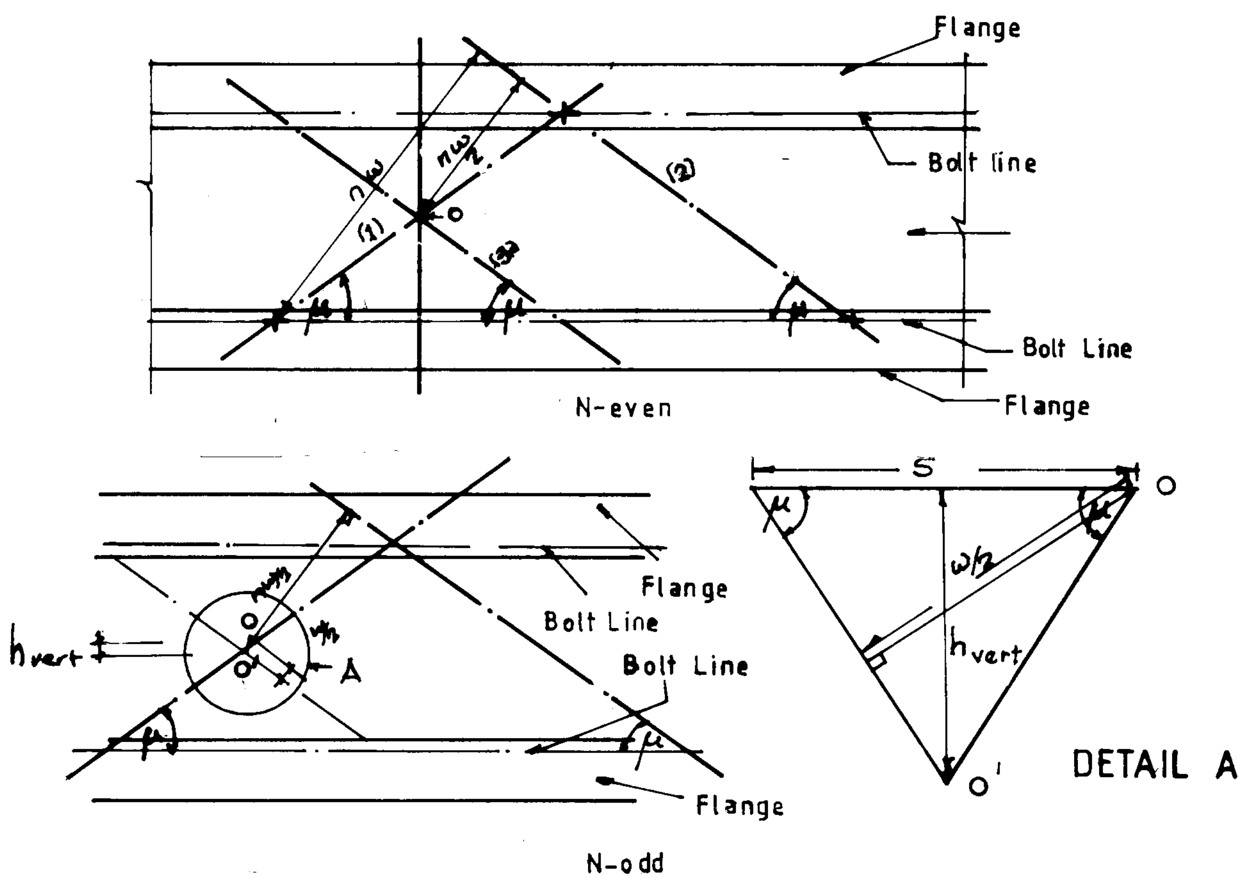

Figure 4 – Determination of common point where two laminations in different layers can start from

Girder Structural Behavior

Theoretical Analysis

A theoretical solution may be obtained by considering every bolt position in the beam as a joint and the material between bolts as a beam member. In this way finite element solution may be applied to the beam to obtain strains and beam stresses in the beam.

Such an analysis has two defects. These are:

i. the process is wieldy and does not lend itself easily to office design.

ii. due to the number of bolts, friction forces arise between members and produces results different from what the above may predict.

There is therefore the need to derive equations for the structure based on the laboratory observations on the beam behavior. The following assumptions are made with respect to the beam behavior.

at each point of intersection of any two diagonal laminations.

iv. Plane sections in the girder before bending, remain plane after bending.

Based upon these assumptions, and the displacement geometry in Figure 5, the general strain-displacement equation for the web lamination may be derived as

$$\varepsilon_w = \frac{\partial u}{\partial x}\cos^2\mu \pm \frac{\partial v}{\partial x}\sin\mu\cos\mu \qquad (3)$$

where $_w$ is the strain in web and u, v are horizontal and vertical displacements. This displacement equation was first derived by Ghaboussi in reference one.

Stresses Due to Moment – Using equation 3 and assumption {iv} above, the effective moment of inertia of the section may be derived as

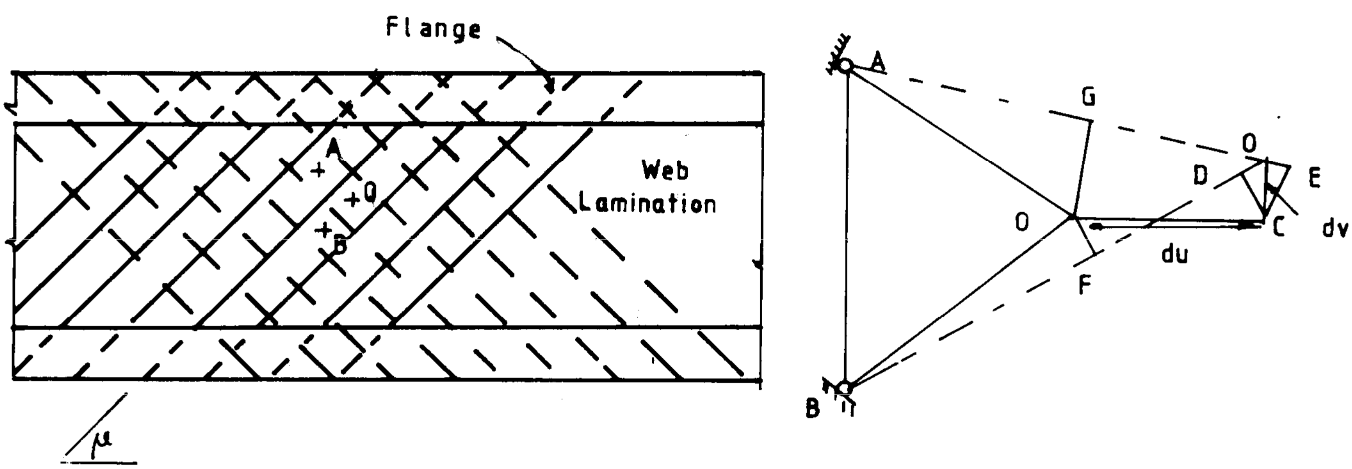

Figure 5 – Displacement geometry in girder

i. The flanges are wide so that there is strain variation across its width.

ii. The web lamination is narrow and strain across its width may be assumed as uniform (i.e., tensile or compressive).

iii Due to the friction between laminations in the two layers, it is assumed that a mechanical joint occurs

$$I_e = mI_w\cos^4\mu + I_f \qquad (4)$$

where I_w is the moment of inertia of the web assuming it is continuous. I_f is the moment of inertia of the flange and m is the ratio of the moduli of elasticity i.e.,

$$m = \frac{E_w}{E_f} \quad (5)$$

The resulting stresses in the flange $_{f,m}$ and the web $_{w,m}$ due to moment M are given as:

$$\sigma_{f,m} = \frac{My}{I_e} \quad (6)$$

$$\sigma_{w,m} = \frac{My}{I_e} m \cos^2 \mu \quad (7)$$

where y is the vertical distance from the neutral axis

Stresses Due to Shear – Just as in other beams, the shear is related to the moment as

$$Q = \frac{\partial M}{\partial x} \quad (8)$$

Using equation 8, it may be shown that

$$\sigma_{w,q} = \pm \frac{2Q}{bwI_e \sin 2\mu}[(A\bar{y})_f + m \cos^4 \mu (A\bar{y})_w] \quad (9)$$

where the same timber is used for flange and web, m= 1 and equation (9) reduces to

$$\sigma_{w,q} = \pm \frac{2Q}{bwI_e \sin 2\mu}[(A\bar{y})_f + \cos^4 \mu (A\bar{y})_w] \quad (10)$$

where $(A\bar{y})_w$ and $(A\bar{y})_f$ are the static moment of area of web and flange respectively about the neutral axis in the girder cross-section.

Similarly, the shear stress in the flange is given as

$$\tau_{f,q} = \frac{Q(A\bar{y})}{I_e \ b_f} \quad (11)$$

Defections – The total deflection of the girder consists of:

i. flexural deflection.
ii. shear deflection.
iii. creep deflection.
iv. slip deflection.

Flexural Deflection — This may be computed using the usual beam deflection formulae for various load conditions and types of support. The flexural rigidity to use is the $E_f I_e$ where E_f *is* the young's modulus of flange timber and I_e is the effective moment of inertia of the girder cross-section.

Shear Deflection — Unlike steel and concrete girders in which their depths tend to be shallow, practical dimensions of the girders are such that they tend to be deep. This means shear deflections cannot be neglected.

To compute the shear deflections, the usual formulae for beams subject to various loading and support conditions may be used. The effective shear rigidity $(GA)_e$ may be computed using the formula

$$(GA)_e = \frac{E_f \ I_e^2}{m\sum_{k=1}^{4} f_k} \quad (12)$$

where m is as given in equation 5. For the same timber for troth the web and the flange, m = 1, thus

$$(GA)_e = \frac{E_f \ I_e^2}{\sum_{k=1}^{4} f_k} \quad (13)$$

where f_k is a function of beam cross-section geometry only. The function f_k is given in references two and three.

Creep Deflection — Creep deflection in any material is a function of stress level and time. Timber tends to creep and research is needed to determine the ultimate amount of creep deflection to be expected for the timber girder. From preliminary survey, doubling the flexural deflection for dead loads seems to give adequate results for the creep deflection.

Slip Deflection — An upper limit for slip deflection may be obtained by knowing the maximum tolerance permitted for the size of bolt hole and computing the product

$$\delta = \sum U \partial l \quad (14)$$

where U *is* the resulting force in the member with the bolt due to a unit load in the direction in which deflection is required and ∂l is the displacement at each bolt, i.e., the tolerance.

Conclusions

1. It has been shown that for a developing country which abounds with wood, and has to import cement and steel, the utilization of wood for bridges is cost effective.
2. The wooden girder chosen for the job, has been developed by the authors and has the advantages enumerated above, over other timber girders for a developing country.
3. By making use of the geometrical relationship developed in the text, the girder can be correctly set out.
4. The use of the structural equations as stated above, enables the structural proportioning for moment, shear and deflection to be effected.
5. Tests conducted at the Building & Road Research Institute, Ghana, reference three and Virginia Polytechnic Institute and State University, Blacksburg, Virginia, have shown that within the elastic range, equations outlined in this paper are adequate in predicting the behavior of the girder under load.

6. A prototype bridge designed using these equations is shown in Figure 6.

Figure 6 — A demonstration bridge showing girder and articulated truck on bridge

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