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Structural Analysis and Design Of Timber Reinforced Structures Using Euro Code: A Case Study of Multi Cell Culverts

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***ABSTRACT** : This study looks at the design, structural performance, and cost of building a triple-cell box culvert reinforced with sustainable timber instead of traditional steel. Using Eurocode standards for timber-concrete composite (TCC) systems, we tested how the structure's top slab, bottom slab, and side walls handle weight and pressure. The structural analysis calculated design loads of 77.78 kN/m for the top slab, 17.06 kN/m for the side walls, and 105.74 kN/m for the bottom slab. These forces caused bending pressures (span moments) of 100.16 kNm, 25.38 kNm, and 175.73 kNm, and peak support moments of 65.15 kNm, 39.84 kNm, and 113.54 kNm, respectively. The highest tearing forces (shear forces) reached 156.13 kN on the top slab, 24.90 kN on the side walls, and 233.44 kN on the bottom slab. To handle these loads safely, we used a uniform reinforcing grid of C24-grade timber sections measuring 100 × 50 mm, spaced at 300 mm center-to-center. To make sure the timber and concrete bond together perfectly, mechanical shear connectors were added along the joints. We used 26 connectors per meter for the top slab, 4 for the side walls, and 38 for the bottom slab. For a fair comparison, we also designed a traditional steel-reinforced culvert using Eurocode 2 standards. This baseline setup required heavy steel bars (Y20 @ 200 mm with Y12 @ 150 mm distribution bars) on both faces of every concrete member. The final financial analysis revealed that the timber-reinforced alternative costs ₦1,543,800, while the standard steel concrete structure costs ₦3,382,000. This represents a massive 54.4% cost reduction without sacrificing any structural safety or performance margins. Ultimately, the findings confirm that Eurocode-compliant timber reinforcement is a reliable, practical, and highly economical alternative to traditional steel rebar for multi-cell culvert projects.*

***KEYWORDS:** Euro code (EN),Timber concrete composite (TCC) , Timber design, concrete design, engineering code of practice, Culverts, Triple cell culverts*

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I. INTRODUCTION

Timber is a naturally occurring, anisotropic, and hygroscopic material whose unique thermal, electrical, and mechanical properties make it an exceptional choice for modern construction (Ezeagu et al., 2015). While traditional wood usage declined with the rise of industrial steel, its high strength-to-weight ratio and self-support breaking length allow it to span large distances with minimal support infrastructure (SkyCiv Engineering, 2019). When seasoned to a moisture content between 7% and 12%, timber functions as an effective electrical insulator, enhancing building safety.

In Timber-Concrete Composite (TCC) frameworks, engineered timber elements are mechanically anchored to concrete sections to optimize structural mechanics (Majić & Rajčić, 2021). Under flexural loads, the concrete layer is positioned in the compression zone, while the timber is utilized in the tension zone. Because concrete possesses negligible tensile strength and is prone to macro-cracking under bending forces, the high tensile capacity of timber offsets this deficiency. This structural pairing makes TCC components a viable structural alternative to conventional steel reinforcing bars.

A culvert is a specialized hydraulic conduit designed to channel water beneath transportation corridors like roads or railways, serving as a cross-drainage bridge or water flow regulator depending on site topography. Culverts are constructed in various geometric profiles including circular, box, elliptical, and pear-shaped forms selected based on site hydraulics, roadway elevations, and earth load requirements.

Designing a culvert structurally requires calculating the precise stresses and strains induced by these external loads to specify adequate reinforcement. To achieve the core aim of this research, a rigorous design framework must be established. First, all dead and imposed gravity loads acting on the multi-cell box components must be identified and calculated. Second, the resulting internal forces specifically the maximum span bending moments and peak cross-sectional shear forces must be systematically evaluated.

Third, these actions must be used to design the composite structure in strict accordance with Eurocode provisions, supported by detailed structural drawings of the slabs and vertical walls. Fourth, a dedicated timber reinforcement bending and cutting schedule must be compiled for all structural components. Finally, an exhaustive economic evaluation must be conducted to compare the total capital cost of this timber alternative against traditional steel-reinforced configurations, proving whether TCC infrastructure can maintain required performance margins while lowering construction expenditures.

II. MATERIALS AND METHODOLOGY

Table 1: Design Information

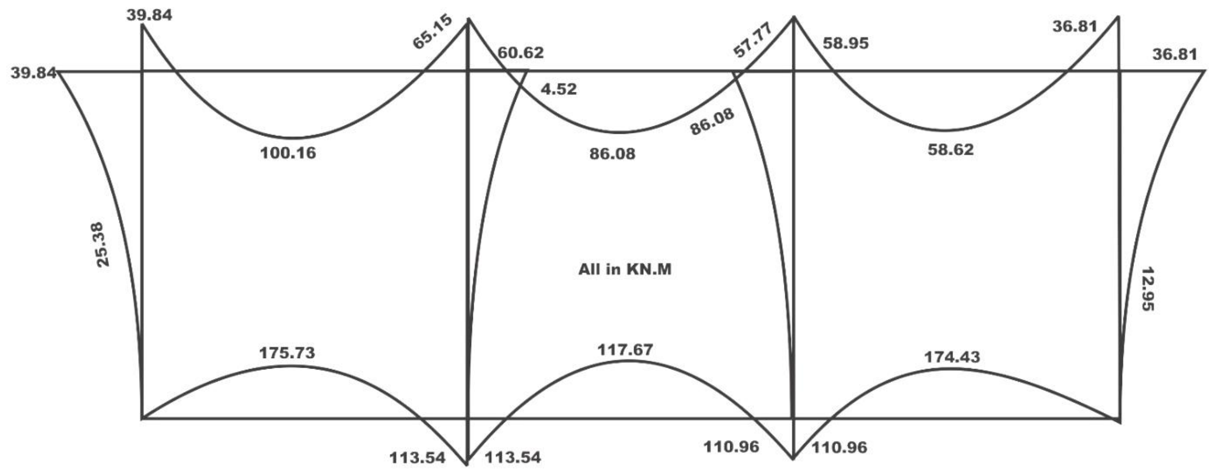
Relevant Design Codes	Eurocode 5, EN 1995-1-1, Connection slip for concrete to timber connections and EN 1995-2, influence of the connection slip in composite action deck plate systems, EN 1995-1-1;8-2, Timber concrete connections in Composite Systems. 1992-1-1, Euro code 2-Part 1-1, Design of Concrete Structure. EN, 1992-1-2, Euro code 2-Part 1-1, Design of Concrete Structure
General Loading Condition	HB Loading Units (30 and 45 units). Specific Density of Timber = 5KN/m^3 Specific Density of Concrete = 25KN/m^3 Density of active earth pressure = 18KN/m^3 Water Pressure = 10KN/m^3 Unit Weight of asphalt concrete = 22.5kN/m^3 Timber grade C24 Characteristic strength of timber = 24Mpa Elastic Modulus of timber = 12Gpa Elastic Modulus of Concrete = 30Gpa Shear capacity of screws= 8kN Tensile capacity of screws = 17KN Characteristic Strength of Concrete = 30N/mm^2 Characteristic Strength of Steel = 500N/mm^2 Effective Pressure for Wheel Load = 1.1N/mm^2 Factor of horizontal active pressure = 0.33

	Concrete cover = 50mm
Factor of Safety	Dead Load (Gk) = 1.35 Imposed Load (Qk) = 1.5 Ultimate design load = 1.35 Gk + 1.5 Qk
Triple Cell Culvert Details	Culvert size = 1.6m by 3m for each cell Depth of Culverts c/c of Top and Bottom Slab = 1600mm (1.6m) Thickness of Earth fill = 1200mm (1.2m) Thickness of Asphalt = 100mm (0.1m) Thickness of slabs = 350mm (0.35m) Chainage Points for Triple Cell Culverts = 0 + 725m

Table 2: Design moments

Element	Maximum support moment (kN.m)	Maximum span moment (kN.m)	Maximum shear (kN)
Top slab	65.15	100.16	156.13
Side walls	39.84	25.38	24.9
Bottom slab	113.54	175.73	233.44

Fig 1. Bending moment diagram



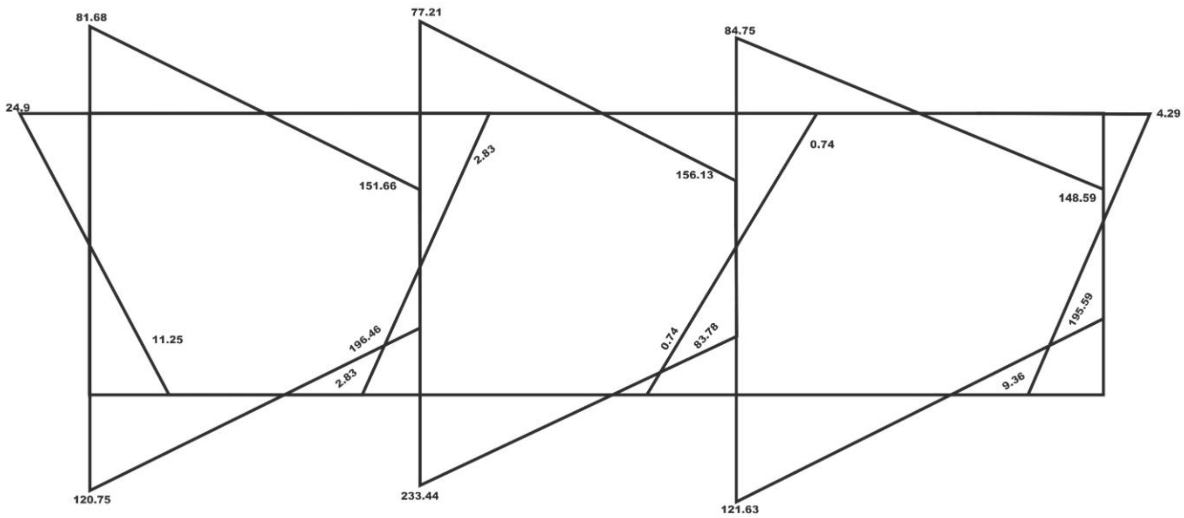


Fig 2: Shear Force Diagram

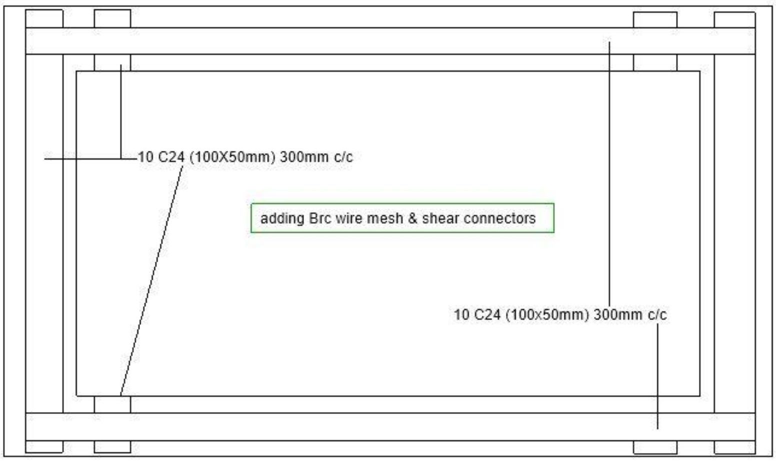


Fig 3. structural detailing of timber reinforcement for all members

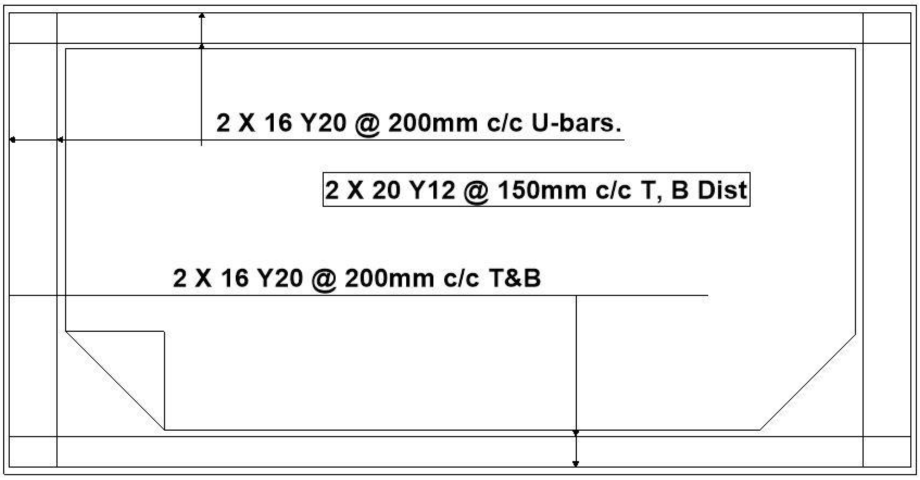


Fig 4. structural detailing of steel reinforcement for all member

IV. RESULTS AND DISCUSSION

During the research, structural analysis was conducted to evaluate the various essentials needed for the proposed culverts. The results of the analysis are summarized in Table 4.1 below.

Table 3: Summary of Result obtained through analysis of Triple Cell Culvert

Structural members	Parameters	Euro code 5	Euro code 2
Top slab	Ultimate design load (Kn/m)	77.78	77.78
	Support moment (Kn/m)	65.15	65.15
	Span moment (Kn/m)	100.16	100.16
	Shear force (kN)	156.13	156.13
	Area of steel required (mm^2/m)		920 (span) 599 (support)
	Area of steel provided (mm^2/m)		1570 (span) 1570 (support)
	Steel reinforcement provided		2×16 Y20 @ 200mmc/c T&B, 2×20 Y12 @ 150mmc/c Dist.
	Timber reinforcement provided	8 C24 (100×50mm) @ 300mm	

Vertical walls	Design moment (Kn/m)	17.06	17.06
	Support moment (Kn/m)	39.84	39.84
	Span moment (Kn/m)	25.38	25.38
	Shear force (kN)	24.9	24.9
	Area of steel required (mm^2/m)		233 (span) 366 (support)
	Area of steel provided (mm^2/m)		1570 (span) 1570 (support)
	Steel reinforcement provided		16 Y20 @ 200mmc/c, 20 Y12 @ 150mmc/c Dist.
	Timber reinforcement provided	10 C24 (100×50mm) @ 300mm T&B	
Bottom slab	Ultimate design load (Kn/m)	105.74	105.74
	Support moment (Kn/m)	113.54	113.54
	Span moment (Kn/m)	175.73	175.73
	Shear force (kN)	233.44	233.44
	Area of steel required (mm^2/m)		1333 (support) 934 (span)
	Area of steel provided (mm^2/m)		775 (support) 725 (span)
	Steel reinforcement provided		2×16 Y20 @ 200mmc/c T&B, 2×20 Y12 @ 150mmc/c Dist.
	Timber reinforcement provided	10 C24 (100×50mm) @ 300mm	

Bar Bending Schedule for Timber Reinforcement

Table 4: Timber Reinforcement schedule details for all structural elements

Element	Length(m)	Section (mm)	Material	Total no	No of members	Total length of wood (m)
1 (top slab)	2.9	Top 50x100	C24 (EC5)	10	3	87
2 (top slab)	2.9	Bottom 50x100	C24 (EC5)	10	3	87
(vertical walls)	1.5	Top 50x100	C24 (EC5)	6	4	36
4 (vertical walls)	2.9	Bottom 50x100	C24 (EC5)	10	4	116
5 (bottom slab)	2.9	Top 50x100	C24 (EC5)	10	3	87
6 (bottom slab)	2.9	Bottom 50x100	C24 (EC5)	10	3	87
TOTAL						**500**

Conversions

Total length of wood needed = 500/3.6

139 lengths of wood needed.

Steel Reinforcement

Table 5: Bar bending Schedule

Bar mark	Size and type	No of each	No of member	Shape code	Length of each (m)	Total length of each (m)
1	Y20	40	3	U- shape	2.9	348
2	Y12	40	3		2.9	348
3	Y20	20	4		1.5	120
4	Y12	11	4		2.9	127.6
5	Y20	40	3	U- shape	2.9	348
6	Y12	40	3		2.9	348

Conversion

Total length of Y20= 816m

Total length of Y12= 823.6m

Total length of Y20 needed = 816m/11.5m

71 lengths of Y20 needed.

Total length of Y12 needed = 823.6/11.5

72 lengths of Y12 needed.

Cost Comparison

Cost for Timber Design

Table 6: price of construction materials for Timber reinforced concrete

Materials	Unit Price (₦)	Prices (₦)
Timber beams (2 by 4)	2200	305,800
Shear Connectors Screws	1000	1,098,000
Brc Mesh	35,000	140,000
TOTAL		**1,543,800**

Cost for Steel Design

Table 7: Price of construction materials for Steel reinforced concrete

Materials	Unit Price (₦)	Prices (₦)
Y20	38,000	2,698,000
Y12	9,500	684,000
TOTAL		**3,382,000**

V. CONCLUSION

The primary objective of this study was to assess and design a timber-reinforced multi-cell culvert in compliance with Eurocode requirements. This final chapter presents a concise summary of the study's key conclusions, contributions to knowledge, major findings, and practical recommendations.
The main conclusions drawn from the investigation are summarized as follows:
The following are the main conclusions drawn from the assessment and design of a timber-reinforced triple cell box culvert using Eurocode standards:

1. Design Loads: The total design loads determined for the structural components of the triple cell box culvert are as follows:
   - Top slab: 77.78 kN/m
   - Vertical walls: 17.06 kN/m
   - Bottom slab: 105.74 kN/m
2. Moment Values: The structural analysis revealed the following:
   - Support moments: 65.15kNm (top slab), 39.84 kNm (walls), and 113.54 kNm (bottom slab)
   - Span moments: 100.16kNm (top slab), 25.38kNm (walls), and 175.73kNm (bottom slab)
3. Shear Forces: The shear forces acting on each member of the culvert are:
   - Top slab: 156.13 kN
   - Vertical walls: 24.9 kN
   - Bottom slab: 233.44 kN
4. Timber Reinforcement Specifications: Timber reinforcement using Grade C24 hardwood is required as follows:
   - Main bars: 100 mm × 50 mm @ 300 mm c/c
   - Distribution bars: 100 mm × 50 mm @ 300 mm c/c This reinforcement specification applies uniformly across all structural members.

5. Shear Connectors: The number of shear connectors per meter for each structural component are:
    - Top slab: 26 connectors/m
    - Vertical walls: 4 connectors/m
    - Bottom slab: 38 connectors/m
6. Cost Comparison:
    - The total cost for the timber-reinforced concrete culvert design is approximately ₦1,543,800,
    - Compared to the steel-reinforced concrete design, which totals approximately ₦3,382,000.

This indicates that the timber-reinforced design is more cost-effective, offering about 54% savings

V Recommendations

The following suggestions are put forth considering the study's findings and conclusions:

1. Adoption of Eurocode 5 in Timber Design because of its extensive design framework and demonstrated structural reliability, Eurocode 5 should receive a lot of consideration when designing timber-reinforced structures.
2. Higher education institutions and professional engineering organizations like the Council for the Regulation of Engineering in Nigeria (COREN), the Institution of Structural Engineers (NIStructE), and the Nigerian Society of Engineers (NSE) are urged to include Eurocode 5 in their continuing professional development (CPD) programs and curricula. This will improve knowledge and proficiency in its real-world implementation.
3. Compared to steel, timber offers environmental benefits because it is a sustainable and renewable resource. Its use as reinforcement can be ecologically responsible if forests are managed well and replanted. To support and promote timber as a structural reinforcement material, professional bodies should start in-depth research and policy discussions.
4. Given that timber-reinforced concrete structures are significantly more economical than their steel-reinforced counterparts, stakeholders in the construction industry should seriously consider timber as an alternative reinforcement material to help reduce overall construction costs without compromising safety or performance.

REFERENCES

Adam C.S and Benjamin F, (2021). Mechanical properties of wood. Wood Handbook- Wood as an Engineering material. General Technical Report FPL-GTR 282. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest product Laboratory, p543

Aguwa, J. I., Chukwu, P. C., and Auta, S. M., (2015). Characterization and Grading of South Eastern Nigeria grown Irvingia gabonensis Timber in Accordance with BS 5268. Journal of Research Information in Civil Engineering, Vol.12, No 2

Alayande T.A, Ede A.N, Aguwa J.I, Ofuyatan O.M, Oyebisi O.M, Oluwafemi J.O (2019). Reliability Assessment of the Nigerian Timber- An Environmental Sustainability Approach in the 21st Century. Journal of Physics Conference Series. 2019,1378 032053

Dias A, Skinner J, Crews K and Tannert T (2016). Timber-concrete-composites Increasing the Use of Timber in Construction. European Journal of Wood and Wood Products 74(3): 443-451

Design of Timber Structure; Structural design of timber-concrete composite structures – common rules and rules for buildings / Project Team CEN/TC 250-SC5.T2. 2018.

EN 1990 (2010) Eurocode: Basis of structural design; German version EN 1990:2002 + A1:2005 + A1:2005/AC.

EN 1991-1-1 Eurocode 1: Actions on structures - Part 1- 1: General actions - Densities, self-weight, imposed loads for buildings.

EN 1991-1-5 Eurocode 1: Actions on structures - Part 1- 5: General actions - Thermal actions.

EN 1995-1-2 (2004) (English): Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design Authority: The European Union Per Regulation 305.

EN 1992-1-1 (2004) (English): Eurocode 2: Design of concrete structures - Part 1- 1: General rules and rules for buildings Authority: The European Union Per Regulation 305.

EN 26891 - Timber structures - Joints made with mechanical fasteners - General principles for the determination of strength and deformation characteristics. ISO EN 26891.

EN338:2003: Timber Structures - Strength Classes, European Committee for Standardization, Brussels, Belgium.

EN384:2004: Structural timber - Determination of characteristic values of mechanical properties and density, European Committee for Standardization, Brussels, Belgium.

Ezeagu C.A, Eromosole A.F, Okoro H, Chukwujekwu U.J and Emetomo T.B (2015). Flexural Strength of Solid and Glue-Laminated Timber Beams. American Journal of Engineering Science and Technology Research. Vol. 3, No. 1, p1-14.

FHWA, Federal Highway Administration (2012). "Hydraulic Design Of Highway Culverts" Hydraulic Design Series Number 5 (HDS 5) Third Edition. Available at www.fhwa.dot.gov/ engineering/hydraulics/software/hy8.

Fragiacomo, M and Schänzlin, J. (2013). Proposal to account for environmental effects in design of timber-concrete composite beams, Journal of Structural Engineering, ASCE, Vol 39, No. 1 pp. 162-167, 2013

Okpara D.I. (2021). Structural Analysis and Design of Box Culvert Along isuaniocha/mgbakwu Road Using Euro Code. Bachelor of Engineering Dissertation, Department of Civil Engineering, Nnamdi Azikiwe University Awka.