Calculate Lightweight Concrete Aggregates for Constructing Bridges

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Abstract. In recent times, the application of lightweight materials in structural engineering, including bridges, has become a common practice. Besides possessing features like thermal insulation and a longer curing period, lightweight concrete provides a significant advantage in the form of reduced weight compared to normal concrete. Consequently, a more lightweight structure translates to an increased span length, reduced seismic effects, smaller abutments, and piers. This article focuses on the calculation of a lightweight concrete mix specifically for bridge applications and examines the efficiency of internal forces in reinforced concrete bridge girders that utilize lightweight concrete. These results can be utilized as a reference when undertaking bridge construction ventures in Vietnam.

Keywords: lightweight concrete, properties concrete, concrete mix, constructing bridges, bridge girders.

1 Introduction

Light concretes are used primarily in bridge construction to reduce the weight of bridges, lower the cost of maintenance, increase throughput, and achieve a certain economic benefit. By implementing lightweight materials, the most significant advantage is observed in the decrease of dead loads. This leads to several benefits, such as widening the bridge deck with little or no adjustment to the existing structure, increasing the structure's resistance to earthquakes, designing longer spans, utilizing smaller fabricated bridge elements, reducing transportation and handling expenses, and lowering foundation and substructure costs. Lightweight aggregates for LWC can be derived from volcanic sources, coal combustion byproducts, or expanded shales, clays, and slates (ESCS). ESCS lightweight aggregates are the most commonly used in modern LWC construction. ESCS aggregates are structurally strong, dimensionally stable, physically durable, light in weight, highly water absorbent and retentive, environmentally friendly, and excellent for crack control [2-4].

The number of bridges built with lightweight concrete has increased in recent years, and this trend is continuing around the world. Lightweight concrete was used in the construction of many large rail and road bridges. The following is a brief description of the most common lightweight concrete bridge projects [5].

To test the practicality and performance of high-strength LWC bridge girders, the Georgia Department of Transportation (GDOT) designed and built the center two spans of the four-span I-85 Ramp crossing SR 34 in Newnan, Ga., with LWC for the AASHTO BT-54 girders and normal weight concrete for the bridge deck. Based on construction experience and monitoring results, GDOT determined that LWC could be applied to construction practice and that LWC provided an effective material for decreasing bridge weight, allowing greater spans to be efficiently constructed. Aside from that, the Stoma bridge is the world's largest span built with lightweight concrete. It is situated in the port city of Bergen in the country's southwest.

In 1998, the Raftsundet bridge became operational as part of the FAST project located in northern Norway. The bridge has a structural type of (86 + 202 + 298 + 125) meters and measures 10.3 meters in width, with a total length of 911 meters. It was commissioned in November of that year. Additionally, there exists a bridge application in China constructed from lightweight concrete [6].

In the present day, the T-beam bridge is a frequently favored option among designers for constructing small and medium-span bridges worldwide. Accordingly, this paper aims to compute the lightweight concrete aggregates necessary for building a bridge that is suited to Vietnamese conditions.

2 Materials and Methods

2.1 Description of bridge

In this study, the bridge girders system is typical of the T-beam with dimensions of the cross-section 12 m and it has simply supported 33m span.

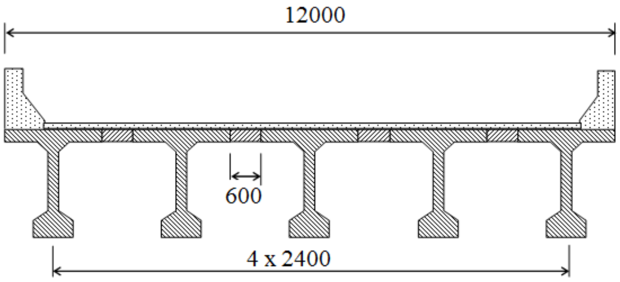


Fig. 1. Superstructure cross section.

The number of main beams is 5 and the distance between them is 2.4 m. Consider the cross-section of a bridge girder as shown below in Fig. 1.

For analysis and design purposes, the prevalent AASHTO LRFD standard is utilized, which is commonly employed worldwide. The vehicular live load comprises a fusion of three distinct load types, namely the HL-93 design truck, HL-93 design tandem, and design lane load [7-10].

2.2 Materials

a) Crushed limestone (CL) sourced from KienKhe (Vietnam) with the particle sizes of 5-20 mm was used as coarse aggregate in the preparation of heavy concrete specimens. While, Keramzite aggregate (KA) (Nhat-Viet Development Industry Co., Ltd, Vietnam) with the particle sizes of 5-20 mm and compressive strength in the cylinder of 6.5 MPa was used as coarse aggregate in the light-weight concrete specimens tested for the current study (Fig. 2).

b) Both heavyweight and lightweight concrete mixtures utilized Quartz sand (QS) obtained from the "Lo river" in Vietnam, possessing a fineness modulus of 3.0, as their fine aggregate. The physical characteristics of the coarse and fine aggregates are listed in Table 1.

c) In this study, ordinary Portland cement (PC) with a 40 Grade was employed, which was produced at the "Hoang Thach" facility located in Vietnam, with a specific weight of 3.15 g/cm^3. Table 2 outlines the physical and mechanical characteristics of the cement tested, whereas the chemical composition results are found in Table 3.

Table 1. The physical properties of both fine and coarse aggregates.

Aggregate type	Aggregate size (mm)	Loose density (kg/m^3)	Dry density (g/m^3)	Water absorption (%)
CL	5 - 20	1445	2.7	0.45
KA	5 - 20	800	1.42	4.0
QS	0.15 - 5	1490	2.65	0.50

Table 2. Physical and mechanical properties of Portland cement "Hoang Thach".

Specific-weight (g/cm^3)	Retained content on sieve 0.09 mm (%)	Surfacea-rea(cm^2/g)	Time of setting (min)		Compres-sivestrength(MPa)			Standard consistency (%)
			Initial	Final	3 days	7 days	28 days	
3.15	5.1	3620	115	365	25.36	38.28	45.4	29.5

Table 3. Chemical properties of Portland cement "Hoang Thach".

Average chemical composition (%)							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on ignition	Other
19.8	4.1	5.4	61.9	2.8	3.2	2.5	0.3

e) Ordinary clean tap water (W) was used for both mixing concrete and curing of test patterns.

2.3 Methods to determine properties raw materials

Calculation method of test concrete mixture compositions are applied in accordance with standard TCVN 9382 – 2012 (Vietnam).

As per the guidelines laid out in the Russian standard, GOST 10181-2014, the workability of a concrete mixture is assessed using the standard slump cone, having dimensions of 100x200x300 mm. The compressive and tensile strengths of the concrete specimens under test are measured using the standard Russian-GOST 10180-2012. The compressive strengths of both heavy-weight and lightweight concrete samples are checked at 3, 7, 14 and 28-day intervals. Additionally, by employing the ACI 318-2005 standard (American), the modulus of elasticity of concrete can be determined using the 28-day compressive strength. Following a period of 24 hours from casting, all test samples are extricated from molds and positioned within a water-curing chamber at a temperature of 25±5^{o}C until it's time for conducting the tests (Fig. 3).

Fig. 2. Keramzite aggregate.

Fig. 3. Mix and pour concrete samples.

2.4 Calculate moments and shears for interior in bridge girder

Internal forces acting on the main girder of the bridge include static load, active load. The standards used in analysis and design are used the AASHTO LRFD standard consists of HL-93 design truck, HL-93 design tandem, and design lane load [11, 12].

Determine permanent loads: The permanent load or dead load consists of the component dead load DC and the surface load DW. The component dead load DC of the bridge consists of all structural dead loads such as two parts of the DC are defined as follows: DC_1-girder self-weight; DC_2 -barrier rail weigh; DW - surface weight.

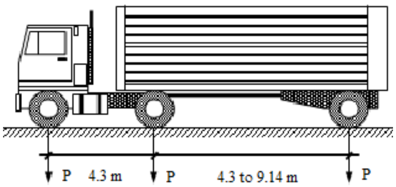
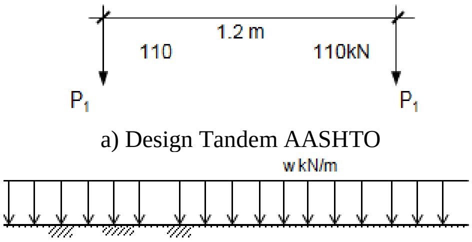


Fig. 4. HL-93 Design Truck AASHTO.



a) Design Tandem AASHTO

b) AASHTO Lane load

Fig. 5. Design load.

The design truck comprises three axles, with the front axle weighing 35 kN and two rear axles weighing 145 kN. The distance between the front and rear axle measures 4.3m, while that of the two rear axles can be adjusted between 4.3 m to 9.0

m to generate the most substantial design force. Fig. 4 illustrates that the tire-to-tire distance in any axle is 1.8 m.

The HL-93 design tandem is comprised of twin axles spaced 1.2 m apart, with each axle weighing 110kN. Fig. 5a illustrates that the distance between the tires in an axle is 1.8m. In terms of the design lane load, it is assumed to have a uniformly distributed load of 9.3 kN/m in the longitudinal direction. As depicted in Fig. 5b, the design lane load is also assumed to have a uniformly distributed load over a 3 m width in the transverse direction.

The determination of live load LL and dynamic load allowance IM involves calculating the AASHTO HL-93 vehicular live load. In accounting for the impact of wheel load from moving vehicles, a dynamic load allowance IM of 33% is considered [13-15]. To calculate and distribute the live load to individual girders, it is recommended, according to AASHTO-LRFD (2012), to employ approximate methods. The live load distribution factors can be determined using equations (1) and (2) in the following manner:

With interior girder:

$$g = 0.075 + \left(\frac{S}{9.5}\right)^{0.6}\left(\frac{S}{L}\right)^{0.2}\left(\frac{K_g}{12Lt_s^3}\right)^{0.1} \quad (1)$$

Exterior girder:

$$g = eg_{interior},\ e = 0.77 + \frac{d_e}{9.1} \quad (2)$$

Where: g - distribution factor; S - spacing of girders; L - span of beam; K_g - longitudinal stiffness parameter, t_s - depth of concrete slab; e - correction factor.

Design vehicle and lane loads should be applied in such a way that extreme force effect is obtained for design. Internal forces acting on the main girder of the bridge by the active load = (truck or tandem) × (1+IM) × g + lane load. (g - is distribution factor method for moment and shear depends on the location of beams, number of designed lanes). The load factors and combinations are provided below [16]: Strength Limit State I: 1.25(DC_1+DC_2) + 1.5(DW) + 1.75 (LL+M); Strength Limit State II: DC_1+DC_2 + DW + (LL+M); Strength Limit State III: DC_1+DC_2 + DW + 0.8(LL+M). In this study, set the off-center load to create the most unfavorable load effect and consider calculating moments for Interior girder with strength Limit State I of option 1 (bridge girders are constructed from Lightweight) and of option 2 (bridge girders are constructed from Heavyweight).

3 Results and Discussion

3.1 Mixture proportioning and properties concrete tested

The purpose of this study is to establish the concrete mixture compositions for lightweight concrete structures that will be utilized in constructing the bridge located in the Northern region of Vietnam.

Compositions of heavyweight and lightweight concretes in this work must possess:

a. The control concrete mix effect on workability is determined by the slump of standard cone of 90 ÷ 150 mm.

b. For both heavyweight and lightweight concrete, the intended average strength was 30 MPa. To determine the compressive strength of the concrete, cube specimens measuring 150x150x150 mm were utilized at 28 days of normal hardening, as illustrated in Figure 2.

c. Using keramzite aggregate to replace 100% of the weight of coarse aggregate in heavyweight concrete and from there is obtained lightweight concrete with a grade of 300 and dry unit weight of 1700-1800 kg/m^3.

Table 4. Mix compositions and properties of fresh concrete.

Mixes	Type of concrete	$\frac{W}{PC}$	Compositions of concrete mixture (kg/m^3)					Slump of fresh concrete (cm)
			PC	KA	QS	CL	W	
HWC	Heavyweight	0.584	368	0	699	1090	215	11.5
LWC	Lightweight		368	574	699	0	215	8.5

Table 4 presents the experimental results of the fresh concrete properties, wherein the mix compositions were based on the standard TCVN 9382 – 2012 (Vietnam). The determination of the cement-to-water ratio through the Bolomey method yielded a constant value of 0.584, which was maintained in all the tested mixes.

Table 4 indicates the impact of replacing keramzite aggregate on the workability of the concrete mixture. The data reveals that the use of keramzite aggregate reduces the workability of the lightweight concrete mix by up to 27.97% in comparison to heavyweight concrete.

The mechanical properties of heavy-light weight concretes at different curing times are shown in Table 5. The average dry density HWC and LWC samples were, respectively, 2350 kg/m^3 and 1815 kg/m^3. The compressive-flexural strengths and modulus of elasticity values of samples tested, respectively, were 38.7 MPa, 3.22 MPa and 28435 MPa for HWC, and 33.6 MPa, 2.85 MPa and 19870 MPa for LWC.

Table 5. Properties of heavy-light weight concretes.

Mixes	Type of concrete	Dry density of concrete (kg/m^3)	Average compressive strength at different ages (MPa)				Average flexural strength at the age of 28 days (MPa)	Elasticity modulus of concrete (MPa)
			3-day	7-day	14-day	28-day		
HWC	Heavyweight	2350	24.3	28.6	30.5	38.7	3.22	28435
LWC	Lightweight	1815	20.4	24.4	30.1	33.6	2.85	19870

The experimental results indicate that, in general, the mechanical properties of LWC samples were inferior to those of HWC samples (control concrete). However, even though the concrete tested still achieved a 28-day compressive strength of more than 30 MPa, the average strength of the LWC samples was only 86.82% of that of the HWC. Notably, the use of ketamine aggregate reduced the dry density of lightweight concrete by 22.77% in comparison to heavyweight concrete. Furthermore, replacing lightweight artificial aggregate in concrete mixes presents an opportunity to recycle industrial waste material that would otherwise have negative environmental impacts, while also lowering concrete costs. Additionally, this can also enhance the engineering properties of lightweight concrete in the construction of bridges in Vietnam.

3.2 Finite element method in order to determine for moments in interior beams for the bridge

The software known as the Finite Element Method is widely used to solve intricate structural problems, although doing so can be quite complex. This technique replaces the continuity of reality with an idealized structure made up of discrete elements (finite elements) connected by nodes. The method is highly versatile, with applications to triangular, rectangular, tetrahedral, solid, and curved elements, whether in single or doubly curved shell problems. Hence, it can solve a wide range of problems, regardless of their complexity [17,18].

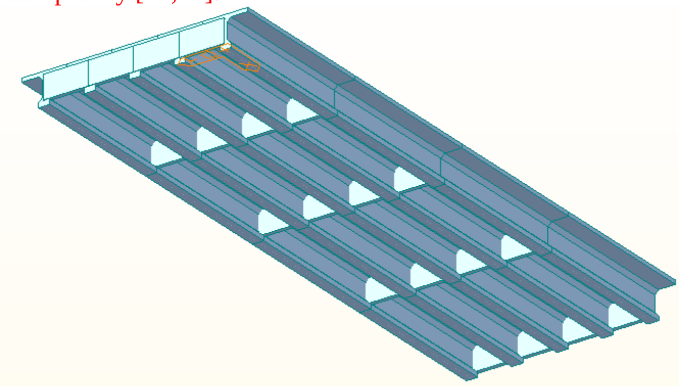
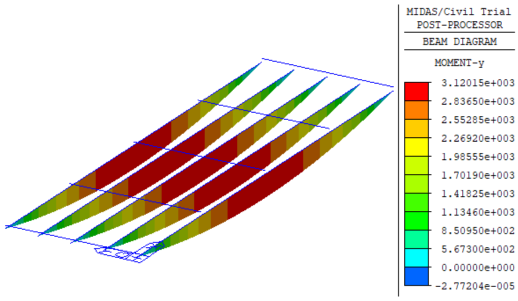


Fig. 6. Modeling of the main girders in T-beam bridges.

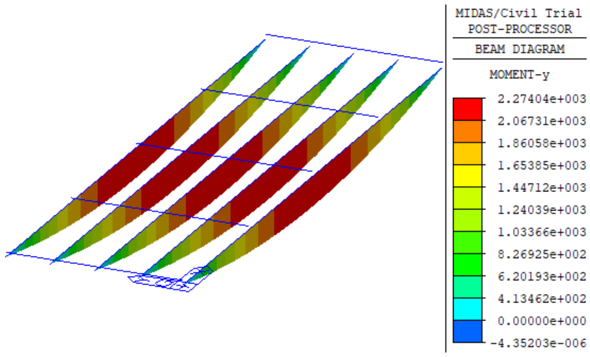
In this particular study, Midas Civil was used to model T-beam girders. Since the main purpose of the study was to analyze bridge superstructures, it was assumed that substructures, such as piers and abutments, did not affect the behavior of the superstructure. Furthermore, the superstructure was taken to be linear-elastic. Fig. 6 shows the 3D finite element modeling mesh for T-beams in the bridge of the solid mode [19,20].

The objective of the study is to compare several load combinations of bridge beam internal forces by heavyweight concrete and lightweight concrete. Detailed calculations are given in Figs. 7-9.

The results showed in Fig. 7 that the difference between the bending moment of the dead load of the bridge girder built from heavy concrete and the bridge girder built from lightweight concrete results was found to be 27.24%. The result demonstrates that the use of lightweight materials for bridge construction has a significant effect on reducing the internal force on the bridge beams when they are of the same size and design load.



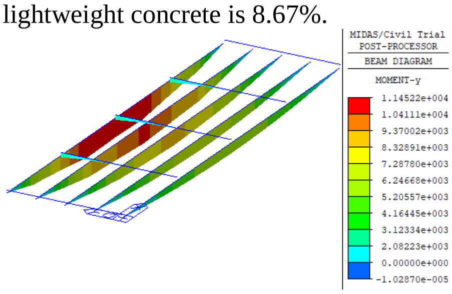
a - M_{max} = 3.12×10^{3}KNm

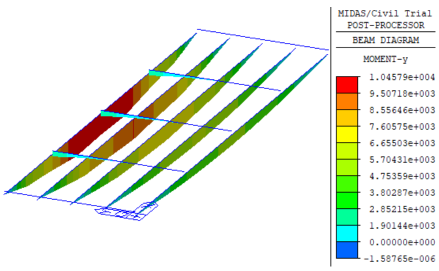


b- M_{max} = 2.27×10^{3}KNm

Fig. 7. The bending moment's internal forces act on the main girder (dead load): a - Heavy-weight, b – Lightweight.

As shown in Fig. 9 above, that bending moments on beams (Heavyweight and Lightweight) with combination I. It is clear that the proportion of bending moments on beams from heavyweight concrete is higher bending moments on beams from lightweight concrete is 8.67%.





a - Mmax= 1.15×10^{4}KNm

b- Mmax = 1.05×10^{4}KNm

Fig. 8. The bending moment's internal forces act on the main girder: a - Heavyweight, b – Lightweight.

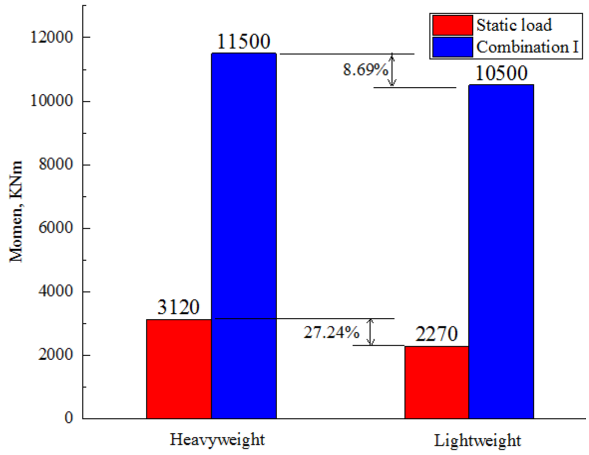


Fig. 9. Bending moments on beams with combinational cases for Heavyweight and Lightweight.

4 Conclusions

Based on the obtained experimental results, the following conclusions can be drawn:

1. The use of lightweight aggregate concrete has the potential to reduce the moment of simple span AASHTO T - girders by up to 27.24% with dead load and 8.67% with combination load I.

2. Bridge beams with lightweight materials will help reduce weight yourself. Therefore, increasing the span length, reducing the number of piers (column) to bring economic efficiency when building.

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