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The behaviour of the Aluminium Bridge with comparison of composite steel bridge

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ABSTRACT

Using aluminium for bridge deck was firstly in 1933 to replace steel and wood deck on Pittsburgh's Smithfield Street Bridge in U.S.A. The use of Aluminium alloys for constructing bridges and bridge decks has much to offer because of their light weight, excellent corrosion resistance. The most famous aluminum alloys that used for bridges are 5086-H116, 6061-T651, 6061-T6 and 6063-T6 as given in AAHSTO. In this research aluminum bridges will be studied. Structural analysis, design, and comparison between two bridges having the same geometric dimensions are implemented. The first bridge consists of steel girders and concrete deck slab. The second one consists of aluminum girders and aluminium deck. Loading and design of the two bridges are according to American Specifications (AASHTO LRFD Bridge 2011.It is concluded that Aluminium Bridge is good competitor for composite bridge because of its excellent corrosion resistance and light weight of super structure. It saves about 82% of the composite bridge weight of superstructures.

Keywords: aluminium bridge, deck, composite, bridge

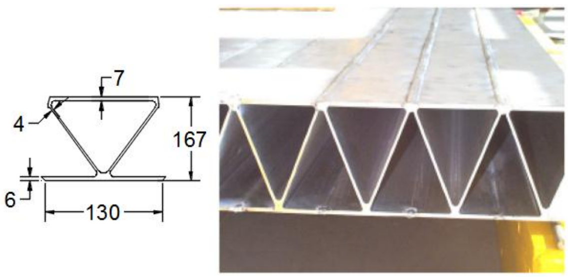
1. INTROUDUCTION

The first use of Aluminum alloys for bridges was in 1933 in U.S.A. many different styles of aluminium bridges already exist in many countries **[1].** Nine bridges were built in North America with aluminium beams and girders between 1946 and 1963**[2].** Many researchers studied the behavior of aluminium deck numerically and experimentally. T.Höglund **[3]** studied replacing damaged concrete decks with aluminium extrusions decks experimentally and theoretically. Kurt P. Thompson **[4]** investigated different types of aluminium bridge decks rehabilitated in the last decades. Tomasz W. Siwowski **[5]** investigated the use of aluminium decks for replacing deteriorated RC deck experimentally.

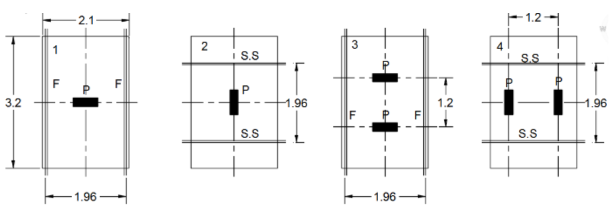
Jeffrey M. Dobmeier et al. **[6]** and Paul C. Misch et al. **[7]** studied aluminium deck panel made of 6063-T6 alloy experimentally and numerically as a first phase study. They also performed a second phase study to evaluate bridge static and dynamic response at field. Ichiro Okura et al**. [8]** studied the connection between aluminium deck to steel girder. Qinghai and Yangon [9] investigated the analysis of aluminium half-opened bridge under live loading effect. Aluminium Association in Germany [10] celebrates with golden jubilee for Germany's first aluminium road bridge. On the other side researchers studied the composite steel bridges to improve behaviour. Zejun Zhang et. Al studied the long-term behavior of steel–concrete composite girders of the real bridge **[11].** Song Lei et al. studied using UHPC to reduce the weight of the bridge deck and improve its crack resistance and durability **[12].**

2. VERIFICATION OF ALUMINIUM DECKS

Tomasz W. Siwowski **[5]** tested an aluminium deck as shown in **Fig.1** which fabricated from Aluminium alloy AW 6005A-T6. This alloy has tensile yield strength of 250.74 MPa and ultimate strength of 280.42 MPa. Four different load cases and boundary conditions were tested. The measured parameter was the deflection for the bottom deck for each different load case at mid span. Four Numerical models for the tested decks are performed using SAP2000 v14.2 program. The numerical models have the same dimensions, materials, boundary conditions and load configurations. Shell element is used to simulate the deck. The results of the numerical models and the experimental tests are given in **Fig.2** which show a good convergence.



a- Cross-section of the Aluminium Deck panel, dimensions in mm



b- Boundary Conditions and Load Configurations, dimensions in m (F: Fixed, S.S: Simply Supported, P =150KN)

Fig.1: Tomasz deck **[5]**

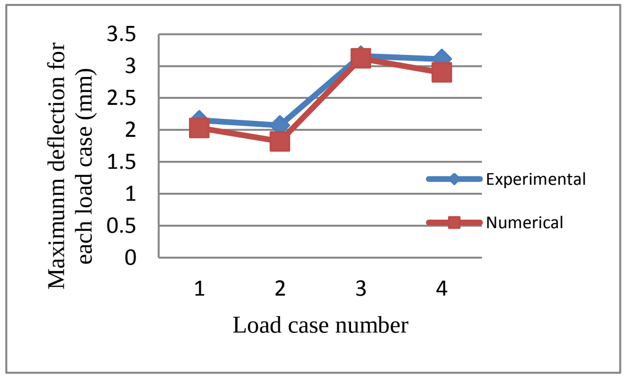


Fig.2: Comparison of Numerical and Experimental Results for Tomasz deck

3. NUMERICAL ANALYSIS

The two types of bridge have five main girders with 20 m simply supported span and spacing 2 m. They have the same plane and cross section as shown in **Fig.3** (a,b and c). They differ in materials of elements as shown in Table1.The cross section of girders is I-beam as shown in **Fig.4** and the dimensions are listed in Table 2. SAP2000 v14.2 program is used to get design requirements (moment, shear and deflection) for different load cases and load combinations. Shell elements are used to simulate decks and frame element for girders. The applicable live loads are AASHTO trucks.

Table 1: Material of The Two Bridges

	Deck	Girders
Composite bridge	20 cm Concrete f'_c = specified compressive strength of concrete= 28 MPa	Steel (Modulus of elasticity = 210000 MPa , Ultimate tensile strength 520 MPa and Yield stress = 360 MPa)
Aluminium bridge	Aluminum alloy 6061-T6 has Modulus of elasticity = 69589 MPa (as in **Fig.1 a**)	Aluminum alloy 6061-T6

Table 2 : Dimensions of Girders Cross Section in mm

	Composite bridge		Aluminium bridge	
	MG	XG	MG	XG
b_{fc}	400	150	480	390
t_{fc}	29	8	34	20
d_w	1120	864	1480	1130
t_w	11	7	17	10
b_{ft}	300	150	480	390
t_{ft}	14	8	34	20

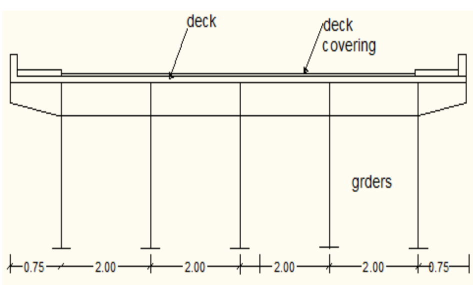


Fig.3a : Cross section of the bridge

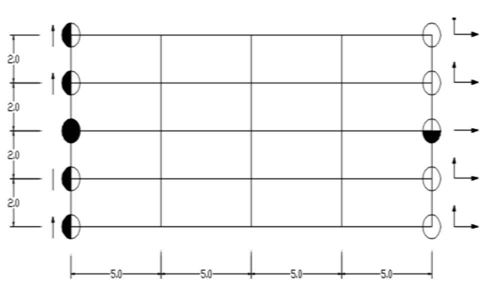


Fig.3 b: Plan of the bridge dimensions in m

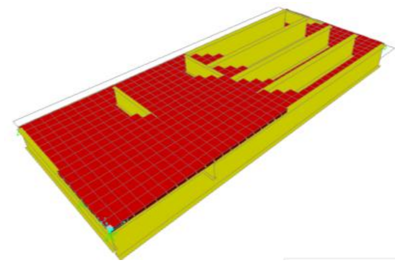


Fig.3c: 3-D model on SAP2000

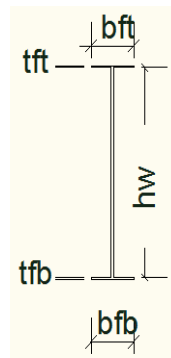


Fig.4: Dimensions of main and cross girder for variant one, dimensions (mm)

4.DESIGN OF THE BRIDGES

4.1 Composite bridge

The design of this bridge was according to AASHTO (LRDF) 2012, section six as composite bridge**. Table (3)** gives the actual straining actions and deflection compared
with the resistance actions.

Table 3: Design of the first bridge

Resistance		Value	unit	Article number in AASHTO	Actual	
Name	type				name	value
Mr	flexural	7905	KN.m	6.10.7	Mu =Σγi.Mi	1654
Vn	shear	1364	KN	6.10.9	Vu=Σγi.Vi	649.5
(ΔF)n	stress	55.03	Mpa	6.6	γ (Δf)	11.03
Δ allowable	deflection	25	mm	2.5.2.6.2	Δmax	24

Where
Mr **:** flexural resistance
Mu : factored moment force at strength I load combination
Vn: nominal shear resistance
Vu : factored shear force at strength I load combination
(ΔF)n : nominal fatigue resistance
γ (Δf) : factored stresses from fatigue II load combination
Δ : deflection

4.2 The second bridge

The design of this bridge was according to AASHTO (LRDF) 2012, section seven. **Table 4** gives the actual stresses and deflection compared with the resistance ones

Table 4: Design of the second bridge

Resistance		Value	Actual
Name	type		
Fr	Flexural stress	282.14	70.43
Fr	Flexural stress	360.9	70.43
Fr	Flexural stress	275.6	67.34
Fr b	Flexural stress	223.1	70.43
Fr	Shear stress	124	44.6
(ΔF)n	Fatigue stress	34.9	15.8
Δ allowable	deflection	25	24.1

4.3 Bridge substructures

The sub structures of the two bridges are estimated and checked structurally.

5.WEIGHT AND COST COMPARISON

After designing the two bridges, weights each type given in **Table 5** .

Table 5: Weight Point of View in (ton)

	Composite bridge	Aluminium bridge
Steel	27.65	_
Aluminium	_	25.9
Concrete	95	_
Asphalt	33.44	_
Epoxy	_	2.85
Total	156.09	28.75

Number of important notes can be observed. Firstly, a significant reduction in the weight of the bridge is achieved by replacing the concrete deck with an aluminum one. This reduction of weight leads to save in columns and foundations. The total weight of bridge one two is 0.18 of bridge one.

From Studying costs of the two bridges for life cycle as in **Table 6**, it is observed that aluminium bridge will be more economic than the composite one.

6.CONCLUSIONS

Two bridges were studied in this paper. The first is steel girders and RC deck the second is aluminium girders and aluminium deck . SAP2000 was used to perform 3D numerical models to get design requirements. Designs according to (AASHTO LRFD 2012) were performed and several conclusions are obtained as following:

- Aluminium behavior is good for bridge girders and bridge decks.
- Using aluminium bridge leads to save 81% in total weight compared with the composite steel concrete one.
- Total cost for the aluminium bridge is about 58% of the composite bridge.
- Deflection governs the design for the two types of bridges.
- Aluminum has a lower weight to length ratio than steel.
- If the comparisons are made based on life-cycle costs, aluminium is a good competitor for steel because of its excellent corrosion resistance

Table 6: Economic study between aluminium and composite bridge

Elements	unit cost in dollar	Bridge one		Bridge two	
		quantity	Price	quantity	Price
Steel (ton)	2222	27.65	61444	_	_
Aluminum(ton)	4444	_	_	25.9	115111
Concrete (m^3)	888	38	33777	_	_
Asphalt (m^2)	111	190	_	_	_
Epoxy (m^2)	77	_	_	190	14777
Protection for steel (ton)	155	27.65	4301	_	_
Foundation and sub structures			293688		117264
Total			3932212		247152
percentage of cost reduction			1		0.628

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