



Material choices and cost optimisation for 3,000m+ span bridges

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Abstract

Weight placement on a bridge span significantly impacts structural reinforcement requirements. A load positioned at the midpoint demands more reinforcement than the same load near a supporting pier. For a 3,000m+ (free span) suspension bridge, this effect becomes particularly pronounced, with indirect costs exceeding the direct cost of the item itself. This paper explores material choices for the main structure, and ancillary components at the midpoint of a 3,000m+ span. It examines the direct costs of these materials and the potential for reducing indirect costs through weight reduction. The materials considered include standard steel grades, high-strength steels, aluminium, glass fibre, carbon fibre, and other lightweight alternatives. For a suspension bridge of this scale, aeroelastic stability is a critical factor. While weight reduction can lower material costs, it also decreases stiffness, thereby reducing the critical wind speed. This paper presents a simplified method for estimating the cost savings achieved through weight reduction.

Keywords: suspension bridge; extreme span; light-weight materials; aluminium deck; aeroelastic stability; quantity reduction; construction cost; carbon footprint.

1 Introduction

The evaluation of material options—including their quantities, weights, and cost impact—for suspension bridge scenarios with a main span exceeding 3,000 metres is based on a simplified reference case: **3000TBS** (Figure 1).

- Bridge Configuration: 3+3 lane motorway crossing
- Deck Design: 44m-wide, 2.8m-deep twin-box steel deck with a 16m air gap, using S355–S460 MPa steel grades
- Main Cables: 46m center-to-center spacing, 1:9 sag-to-span ratio, with a breaking strength of 1,960 MPa
- Additional Elements: Wind fairings and inspection walkways (not shown)

- Structural Weight: 32.2 tons/m (including cables, deck, and miscellaneous components)
- Aeroelastic Stability: 70 m/s critical wind speed (flutter threshold)
- Support Structures: Towers and anchor blocks made of C50 concrete
- Economic & Environmental Impact: Estimated construction cost: €3.0 billion, Carbon footprint: 600,000 tons CO₂ emissions

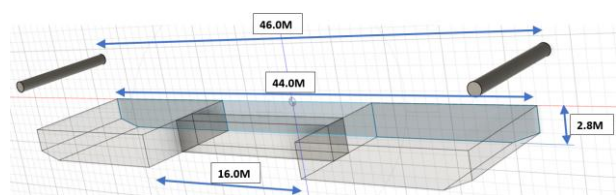


Figure 1. 3000TBS cross section

Major conceptual alternatives and minor design variations will be analysed, primarily focusing on weight, loads, costs, and carbon footprint. Secondly, the impact on system stiffness and wind stability will be considered. Costs and carbon footprint will be divided into direct costs, representing the item itself, and indirect costs, arising from the additional reinforcement required to support the added weight.

2 Reference bridge projects

For the study of the reference case 3000TBS the following suspension bridge projects are referred:

1. Great Belt Bridge, Denmark, 1,624m monobox bridge deck (Figure 2), [1]
2. Langenuen Bridge (project), Norway, 1,220m, monobox in aluminium [2]
3. Canakkale Bridge, Turkey, 2,023m twin box deck [3]
4. Sulafjord Bridge (project), Norway, 2,710m, twin-box bridge deck (Figure 4), [4]
5. Messina Bridge (project), Italy, 3,300m triple-box deck [5]
6. 2,500m suspension bridge (study) Japan monobox bridge deck with CFRP cables [6]
7. 3000MBS (option of this study), 3,000m span, monobox bridge deck (Figure 3) (note: technically unfeasible).



Figure 2. The Great Belt Bridge, Denmark

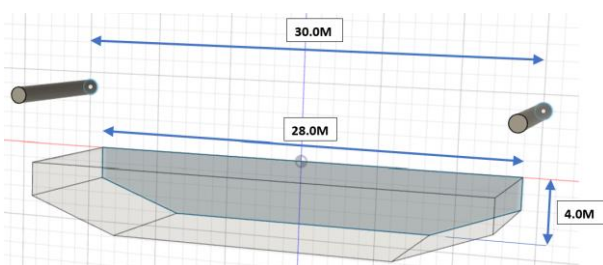


Figure 3. 3000MBS cross section



Figure 4. Sulafjord 2710m (illustration D+W/AMC)

3 Collateral effects

Weight reduction has several collateral effects on loads, material quantities, cost, CO₂ emissions, bridge stiffness, and aeroelastic stability. This study provides a brief assessment of these aspects. However, the accuracy of the quantification is limited, as no FEM programme has been used, which would be required for more reliable results. Consequently, the findings presented here should be regarded as indicative only.

The impact of replacing a material with a lighter alternative can be relatively straightforward to describe in terms of structural loads, material quantities, and construction costs. Simplified formulas for such assessments are available, for example, in [7]. However, other complex factors may be equally important, including risk mitigation (reliability), durability, maintenance, stiffness, and wind stability. Only a limited selection of these topics will be addressed in this study.

3.1 The importance of system stiffness

The stiffness of the main span of a suspension bridge can be categorised into vertical stiffness, lateral stiffness, and torsional stiffness. In this article, lateral stiffness—which is primarily provided by the sway resistance of the main cables and, to a lesser extent, the horizontal flexural stiffness of the girder—is of lesser importance and will not be discussed.

Torsional stiffness is primarily influenced by the separation of the two main cables. This separation creates an equivalent resistance to torsional deformation, as the elongation or shortening of the cables in a torsional mode alters the forces and stabilises rotation. The torsional stiffness of the closed steel box girder is relatively insignificant for very long spans. Torsional stiffness plays a major role in the aeroelastic stability of the bridge.

Vertical stiffness affects the extent of vertical deformation due to traffic loads. However, for a 3,000m span, the deflection remains relatively small and is not a primary design constraint.

A reduction in weight leads to a corresponding reduction in stiffness. This effect will be briefly evaluated in the following sections. For the Great Belt Bridge [1], the stiffness of the cables resisting bridge deck torsion already accounts for two-thirds of the total torsional stiffness. In the 3000MBS option, the deck's torsional stiffness may only contribute 20% of the total stiffness, and in split twin-deck structures, the girder stiffness may constitute as little as 5–10% of the total stiffness.

3.2 Wind stability

For suspension bridges with short to moderate spans a mono-box girder can be designed with a relatively shallow depth. From the Great Belt Bridge, which features a 4.3m-deep mono-box bridge deck, it was stated that further depth reduction was not feasible due to the torsional stiffness required for aerodynamic stability [1].

In general, greater stiffness is beneficial, including in terms of aeroelastic behaviour. However, it is important to clarify the definition of stiffness in this context. For wind-induced phenomena such as flutter, the bridge's natural frequencies are a more advanced parameter than stiffness alone.

The natural frequency of a system is approximately the square root of the element stiffness divided by its mass. For a cable, the stiffness depends on the tensile load, which is directly proportional to the weight it carries. Consequently, a reduction in weight affects both the numerator (stiffness) and the denominator (mass) in the frequency equation. As a result, weight reduction may have a limited impact on the bridge's natural frequency.

Aeroelastic instability caused by flutter can only be accurately estimated through a combination of FEM analyses, determination of modal shapes and frequencies, and CFD simulations to assess aerodynamic derivatives. For the purposes of this article, very rough assumptions have been made for illustrative purposes.

For a 3,000m span, it may be the coupling of various natural modes that could ultimately lead to

the bridge reaching a critical state under sufficiently strong winds. In this article, we assume that the 1st asymmetrical vertical bending and 1st asymmetrical torsion are the most critical factors for stability.

The aerodynamic instability of box girders is typically of the classical flutter type, which involves a 2 Degrees Of Freedom system (bending/torsion) [8], p.6. Based on this, an active control system [8] 5.3 suggests that such a system can enhance the critical wind speed by 50% or more. This means that the single-box option (3000MBS) could achieve sufficient stability.

The critical wind speed is found to be 38% higher with a slotted box girder [8], p.6. In this study, since the slot width is increased, the wind speed increase is closer to two-thirds, bringing it to 70 m/s.

4 Weight reduction options

For the 3000TBS base case suspension bridge, several options for reducing the main span weight are outlined below. For each option, a rough estimate of the quantities and associated bridge costs is provided. These simplified estimates are open to interpretation and should be viewed as indicative only. Numerous additional parameters, not covered in this study, need to be considered for more accurate estimates. The cost implications are outlined in Section 5.

4.1 Bridge deck steel grade

For the Messina Bridge [5], a combination of S355, S420, and S460 was selected, with the assertion that using only S355M would result in an additional 18% increase in the weight of the steel deck. For the 3000TBS discussed in this article, a mix of S355 and S460 has been assumed, meaning the design is already optimised.

For the sake of argument, consider a less optimal version of the 3000TBS, where no steel grade optimisation is applied. In this case, a 10% increase in the steel deck quantity would add $13.6 \times 10\% \times 1.47 = 2.0$ tons/m to the total load, or 5.3%, which corresponds to a 2.1% increase in indirect costs (€63 million). This increase in cost far exceeds the direct cost savings from using lower-grade materials.

4.2 Perforated steel trough

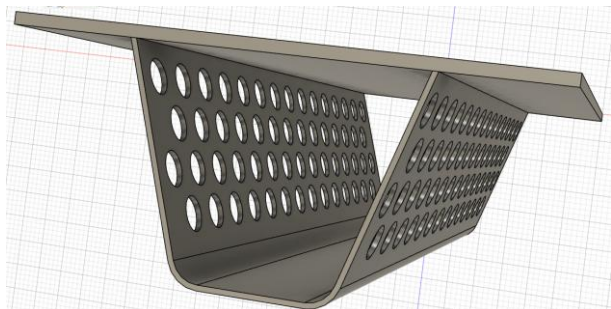


Figure 5. Perforated steel trough

The orthotropic steel deck offers numerous well-established advantages with few drawbacks. The closed troughs are a crucial component of these benefits; however, the webs may provide more shear strength than necessary. The solution is to perforate the webs—reducing, for example, one-third of the web material—without significantly affecting the overall performance. For the 3000TBS bridge deck, this modification results in a total weight reduction of 0.4 tons/m. The cost of punching these holes is estimated to be between €2 and €4 million, whereas the savings in indirect bridge costs amount to €19 million.

4.3 Aluminium bridge deck

The aluminium alternative weighs only one-third of steel and has approximately two-thirds of the strength. When combined, these properties result in a significant weight reduction. In this study, the weight of the aluminium bridge deck is estimated to be 68% of the steel alternative, as detailed in the 3000TBA weight and cost calculation in Section 5.

For reference, the weight of the aluminium deck on the Langenuen Bridge is reported to be between 63% and 75% of the steel alternative [2].

However, aluminium presents several challenges that must be carefully considered, including lower fatigue performance compared to steel, welding complexities, greater thermal expansion (2.4 times that of steel), and a higher CO₂ footprint (4 tons of CO₂ per ton of aluminium vs 2 tons per ton steel).

4.4 Bridge parapets

Bridge parapets are traditionally made from steel. For a large bridge, it will probably be required with H4 class barriers, which are not shelf products in

aluminium. A H4 steel parapet may weigh 90 kg/m (e.g. Birsta 3PH4b).

Based on comparison of steel and aluminium barriers for the lower class H2 it is estimated that an aluminium barrier class H4 will weigh 45% of the steel alternative, i.e. 40 kg/m. For totally 4 barriers along the 3000TBS bridge span, the weight saving comes at 0.20 tons/m equivalent to a cost reduction of €10 million from the indirect effect.

For the main span parapets total steel quantity, the direct cost could be €4 million, and estimate that aluminium will increase direct costs by 25%, an overall saving thus €9 million.

4.5 Pavement

The pavement on the bridge deck is crucial to the overall value of the bridge, as any issues related to safety or comfort can diminish its worth. Therefore, the choice of pavement material should not be experimental. However, the most likely system for steel decks—two layers of high-quality mastic asphalt with a standard thickness of 60mm ([1], p. 193)—is a costly decision for a 3,000m span.

The thickness may be reduced to 45mm without significantly compromising overall quality. This reduction results in a weight saving of 0.8 tons/m, leading to an indirect cost saving of €38 million.

The surface regularity of steel decks is typically excellent. As an alternative, a thinner, high-quality mastic system could be applied with a nominal thickness of only 10mm. Compared to the 60mm asphalt reference, this would result in a weight reduction of 2.6 tons/m. The savings in indirect costs would be substantial—€120 million. One slight drawback of reducing the pavement thickness is that the fatigue stresses in the deck plate will increase.

4.6 Inspection walkways and wind fairings

Along the outer edges of a suspension bridge, inspection walkways are often provided. For short-span suspension bridges, the walkway may even be an integrated part of the closed steel box, meaning the bridge deck is widened to accommodate space for the walkway. For large-span suspension bridges, to ensure optimal aeroelastic performance, including high critical wind speed

resistance (flutter) the bridge deck will require a tailored geometric shape. This can be achieved by shaping the main structure to meet wind demands.

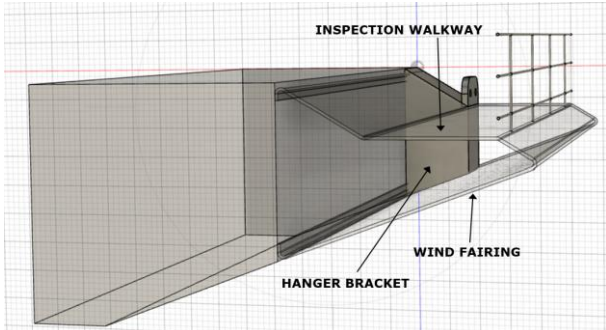


Figure 6. Inspection walkway and wind fairing

An alternative option involves a composite glass-fibre sandwich deck (Figure 6), approximately 35mm thick, similar to the one built for a pedestrian bridge attachment in Aalborg, Denmark (Figure 7) [9].



Figure 7. Kulturbroen Aalborg (design: COWI)

This sandwich plate weighs about 15 kg/m². The combined wind fairing and inspection walkway shown weighs only 100 kg/m, which replaces 600 kg/m if integrated with the main steel structure. For the two external bridge sides, the total weight saving is 1.0 tons/m. This leads to an indirect cost saving of €48 million, while the direct cost for two 3,000m long sections is €20 million. The direct cost of the steel alternative is estimated at €40 million, meaning the total saving amounts to €68 million.

In terms of wind stability enlarging the main steel seems beneficial, as it increases the torsional stiffness of the bridge deck. However, the author disagrees, as the additional torsional stiffness comes at the cost of an increased torsional mass moment of inertia, which is negative. For a wide twin box girder, the primary torsional stiffness is derived from the main cable vertical stiffness. In

such cases, adding mass at the outer edges reduces the torsional eigenfrequency and lowers the critical wind speed.

In Figure 6, note the discrete brackets for the hanger attachment, which are far more economical than widening the main structure along its entire length to achieve sufficient distance between the traffic lanes and the cables.

4.7 Main cable steel grade

It is evident that using the highest grade of cable steel is an option worth examining in detail. While breaking strengths of up to 2,550 MPa are achievable, factors such as cost, technical performance, supply reliability, and lead times must also be considered. For these reasons, a more practical lower grade is typically selected for suspension bridge cables. For the Messina Bridge, an increase in steel grade from 1,860 MPa to 1,960 MPa resulted in a 9% reduction in cable quantity [5]. In this article, a 1,960 MPa grade has been used in the 3000TBS calculations, as it represents the current industry standard (e.g., Canakkale Bridge, Turkey [3]). If a 2,060 MPa grade were used instead, the required cable quantity would be reduced by 8%. The direct cost implications may be neutral or slightly negative due to the higher cost of the material, however the indirect cost savings, amount to €40 million. For Sulafjord 2,800m study, the cable quantity reduced by 6% by increasing from 1,860 MPa to 1,960 MPa [10]. The impact on wind stability is considered neutral. The second bending and torsion modes are typically more critical, and the axial stiffness of the cables has little influence on these. Reduced weight at the outer edges of the deck decreases the torsional mass moment of inertia, which is positive per se.

4.8 Variable main cable cross section

Traditional suspension bridge cables are typically designed with a constant cross-section, despite the fact that the normal force at the pylon top is approximately 10% higher than at the lowest point at mid-span.

Additionally, significant secondary stresses occur due to cable roll at the pylon top. Corrosion of wires has also been a durability concern, particularly at the lowest points where water tends

to accumulate. However, with modern wrapping and dehumidification methods, the risk of corrosion can be effectively controlled. Given these factors, it is worthwhile to explore design options where the cable cross-section is reduced in proportion to the decreasing normal force from the pylon top to mid-span.

4.9 Main cable sag-to-span ratio

The sag-to-span ratio used in these calculations is 1:9, which is common practice. For reference, the 1,624m span of the Great Belt Bridge ([1], p. 177) employs this ratio, where it is considered optimal. However, in the author's opinion, the most cost-efficient solution for a 3,000m span would likely be a ratio of 1:8. Comparing a bridge with a 1:8 ratio to the 1:9 reference, the indirect cost savings amount to €75 million. However, the higher pylons would increase costs by €38 million.

4.10 Main cable transverse position

It may seem tempting to use multiple cables of lesser diameter for wide bridge decks, in order to more optimally support the cross girders. However, studies suggest that the best position for the main cables is at the outer edges of the deck. For the Messina Bridge, alternatives with internal main cables showed significant reductions in the critical wind speed [11].

4.11 Main cable of CFRP

The use of carbon fibre-reinforced polymer (CFRP) cables for long-span suspension bridges has been extensively studied. In a 2,500m span study [6], the weight reduction of the cables themselves was found to be significant. Even when accounting for a substantial structural load beneath them, an overall weight reduction of 20% can be achieved. However, the reference study also indicated a 10% reduction in critical wind speed.

4.12 Cross girders

As the 3000TBS cross girders at mid-span are primarily required for transverse bending, they are assumed to consist of slender 2.8 x 1m boxes made of 25mm plates. For the sake of argument, consider that the plate thickness can be reduced by 5mm. This would result in a total steel weight saving of

approximately 0.4 tons per metre of bridge, leading to an indirect cost reduction of €29 million. The cross girders of the Messina Bridge [5] are quite substantial, consisting of 4.6 x 3.7m box girders with a thickness of 25mm, spaced at 30m intervals. The 3.7m dimension aligns with the typical diaphragm spacing of the longitudinal box girders.

4.13 Central clamp



Figure 8. Great Belt Bridge, central clamp

Some bridges feature central clamps that connect the lowest point of the cable to the deck at midspan. These provide various benefits, but a significant drawback for a 3,000m suspended span is that they introduce additional loads into the deck structure, necessitating extra steel material. For the Great Belt Bridge, this additional steel amounts to approximately 260 tons. While the direct cost of this may be around €2 million, if a similar quantity were required at the midpoint of a 3,000m span, the resulting indirect (additional) would be €8 million.

According to [1], p. 175, the clamp improves the critical wind speed by increasing the bridge's anti-symmetrical stiffness. The effect is not significant to a 3,000m span, and may even be slightly unfavourable. For the Messina Bridge [11], analysis indicated a 1-2 m/s reduction in the critical wind speed when the connection was included in the model.

5 Calculation principles and comparison

5.1 Comparison of alternatives

The 3000TBS reference is compared with the following alternatives:

- 3000MBS mono-box steel

- 3000TBSL twin-box steel low weight (optimised)
- 3000TBA twin-box aluminium deck
- 3000TBA/S twin-box aluminium with orthotropic steel deck

Further characteristics can be seen in Table 1.

The CO2 consumption is estimated at 600,000 tons for the 3000TBS, based on an upscaled estimate for the Sulafjord Bridge [11]. The differences indicated below are based on the assumption that the indirect CO2 amount is proportional to material quantity, while the direct CO2 amount corresponds to the material type.

5.2 Cost assessment

The estimated cost impact of the various alternatives suggested in Section 4 of this paper is based on a simplified approach, as follows:

The total bridge cost for the 3000TBS solution is

based on a 3,000m main span, a total length of 4,400m, and a twin-box steel bridge deck with a 46m cable spacing. The total weight at midspan is 32.2 tons/m, increasing to 38.2 tons/m when including traffic load. The design assumes a 1:9 cable sag-to-span ratio, concrete pylons and anchor blocks, and a total construction cost of €3.0 billion.

Based on experience, the following distribution of cost shares may apply for the 3000TBS:

- Cable structures: 37%
- Pylons: 19%
- Bridge deck: 22%
- Anchor blocks: 15%
- Miscellaneous: 7%

For the discussed weight reduction, it is assumed to have a full effect on cable structures and anchor blocks, a partial (50%) effect on pylon costs, and no effect on the remaining components.

Table 1. Comparison table

	3000MBS	3000TBS	3000TBSL	3000TBA	3000TBA/S
	Mono-box	Twin-box	Twin box Low weight	Twin box Aluminium	Twin box Alu/Steel
Cable spacing	32m	46m	48m	50m	49m
Cable area	2 x 0.70 m ²	2 x 0.775 m ²	2 x 0.66 m ²	2 x 0.62 m ²	2 x 0.65 m ²
Cable weight	2 x 5.5 tons/m	2 x 6.1 tons/m	2 x 5.2 tons/m	2 x 4.9 tons/m	2 x 5.1 tons/m
Deck weight	11.2 tons/m	13.6 tons/m	12.0 tons/m	9.3 tons/m	10.7 tons/m
Longitudinal metal	9.5 tons/m	10.2 tons/m	9.6 tons/m	6.9 tons/m	8.3 tons/m
Transverse metal	1.7 tons/m	3.4 tons/m	2.4 tons/m	2.4 tons/m	2.4 tons/m
Hangers and clamps	2 x 0.2 tons/m	2 x 0.2 tons/m	2 x 0.2 tons/m	2 x 0.2 tons/m	2 x 0.2 tons/m
Pavement	3.2 tons/m	2 x 1.6 tons/m	2 x 1.2 tons/m	2 x 1.6 tons/m	2 x 1.6 tons/m
Inspection walkways	2 x 0.6 tons/m	2 x 0.6 tons/m	2 x 0.1 tons/m	2 x 0.2 tons/m	2 x 0.2 tons/m
Bridge parapets	3 x 0.15 tons/m	4 x 0.15 tons/m	4 x 0.05 tons/m	4 x 0.05 tons/m	4 x 0.05 tons/m
Wind fairings			2 x 0.1 tons/m		
Miscellaneous	1.0 tons/m	1.0 tons/m	1.0 tons/m	1.0 tons/m	1.0 tons/m
Total permanent	28.5 tons/m	32.2 tons/m	26.8 tons/m	24.3 tons/m	26.1 tons/m
Traffic	2 x 3.0 tons/m	2 x 3.0 tons/m	2 x 3.0 tons/m	2 x 3.0 tons/m	2 x 3.0 tons/m
Total load	34.5 tons/m	38.2 tons/m	32.8 tons/m	30.3 tons/m	32.1 tons/m
Total load/38.2 tons/m	90.3%	100.0%	85.9%	79.3%	84.0%
Load reduction	-9.7%		-14.1%	-20.7%	-16.0%
Indirect cost	-4.0% = -0.12 bill EUR		-5.8% = -0.17 bill EUR	-8.5% = -0.26 bill EUR	-6.6% = -0.20 bill EUR
Direct cost	-0.03 bill EUR		-0.02 bill EUR	+0.10 bill EUR	+0.07 bill EUR
Cost	2.85 bill EUR	3.00 bill EUR	2.81 bill EUR	2.84 bill EUR	2.87 bill EUR
Vcrit	45 m/s	70 m/s	68 m/s	65 m/s	67 m/s
Indirect CO2	-58,000 tons		-85,000 tons	-124,000 tons	-96,000 tons
Direct CO2	-14,000 tons		-5,000 tons	+56,000 tons	+37,000 tons
CO2	528,000 tons	600,000 tons	510,000 tons	532,000 tons	541,000 tons

Furthermore, the cost savings due to quantity reduction are assumed to be only two-thirds effective, as there are lump-sum costs beyond those directly proportional to quantity. The load reduction ΔL (in %) refers to the total load of 38.0 tons/m. For a given load reduction ΔL , the corresponding cost savings will be: $\Delta_c = \Delta_L \times 2/3 \times (0.37 + 0.5 \times 0.19 + 0.15) = 0.41 \times \Delta_L$.

This factor should be multiplied by the total cost of €3.0 billion. It may be considered a prudent estimate, as the actual cost savings could be more proportional to weight than suggested in this article, meaning the potential savings might be larger.

An apparent load reduction of 1 ton/m will actually result in a reduction of 1.47 tons/m (as the main cable weight also decreases accordingly) which is $1.47/38.2 = 3.8\%$. This leads to an indirect cost saving of $0.41 \times 0.038 = 1.6\% = €48$ million.

5.3 Review of results

The 3000MBS monobox is included solely to indicate the cost premium of transitioning from a monobox to a twin-box suspension bridge. However, due to its inferior wind stability, this solution is not feasible. Only with active damping systems that can control stability might monobox girders become viable for such large spans.

The optimised twin-box solution, 3000TBSL, results in a cost saving of €0.19 billion, which is significant. The conclusion is that studying various weight-reduction options will be crucial. The 3000TBSL assumes a slightly reduced pavement thickness, aluminium crash barriers, inspection walkways and wind fairings not made from main structure steel, and cross girders tailored to reduce adverse Vierendeel bending stresses.

Additionally, the carbon footprint is significantly improved compared to the 3000TBS reference. The critical wind speed is slightly reduced by about 2 m/s, which is almost inevitable. The cross girders have been extended by 2m to enhance wind stability. This optimisation can be considered low-risk and follows common practice.

The aluminium alternative, 3000TBA, further reduces total costs, but introduces higher risk, which must first be studied and managed. The

weight reduction significantly lowers the critical wind speed, even though the deck width has been increased by 4m to partially recover the stability loss.

Fatigue and thermal expansion pose new challenges that need to be addressed. For the Langenuen Bridge [2], many of these issues have already been resolved, although this project's bridge span is much shorter. The 3000TBA has a carbon footprint lower than the 3000TBS reference, even considering that aluminium, per tonne, has about twice the CO₂ consumption of steel.

The 3000TBA/S will avoid the direct issue of fatigue from vehicle loads, as the deck plate is standard orthotropic steel, thus presenting a reduced risk compared to the full aluminium solution. However, the difference in thermal expansion between aluminium and steel introduces new challenges.

6 Weight reduction – where?

6.1 Within the main span

As observed with the central clamp, additional weight in the middle of the large 3,000m span is undesirable and should be avoided. Towards the pylons, the negative effects of weight gradually diminish, and near the pylon, the indirect costs are much lower. Given that the direct costs are still significant, weight reduction should only be applied where it leads to substantial savings in indirect costs.

Consider the variation to be applied only to the central 2,000m of the main span. In this case, the indirect cost saving would be 8/9 of the saving if applied to the entire 3,000m length.

6.2 Within the side spans

The side spans are almost arbitrary choices, as they primarily function as backup spans for the main span. For example, it would not result in additional global bridge loads if the side spans were heavier than the main span (per linear meter). Therefore, any optimisation applied to the main span does not need to be carried out for the side spans.

7 Conclusions

The study highlights the importance of weight minimisation in the middle of a 3,000m suspended bridge span. Weight limitation is crucial for both the main structure and ancillaries. For an inexpensive construction, such as a concrete safety barrier, the direct cost of 1 ton of this structure may be as low as €250, while the indirect cost accumulates to €30,000. The standard orthotropic steel deck should be provided only below the heavily loaded traffic lanes (1-2 in each direction). The deck beneath the light vehicle lanes and emergency strips should be lighter. Cross girders should be few, deep, but narrow (e.g., I-girders), serving only to secure transverse bending between opposite hangers.

The steel deck may be fully or partially replaced by aluminium, resulting in a significant overall cost reduction. Fatigue issues should be addressed through careful detailing. Ancillaries, such as inspection walkways, wind fairings, etc., should be made from GFRP. Crash barriers may be constructed from aluminium reinforced with pretensioned steel cables. The pavement for vehicle lanes should consist of thin composite materials, 10mm in thickness. A rough comparison between a conventional 3,000m main span suspension bridge design and the completely optimised design outlined above suggests an overall potential cost reduction of around 20% for the latter option. The central clamp, which connects the lowest point of the cable to the deck at midspan should not be used for a 3,000m span, as it incurs a significant cost penalty.

Suspension bridges are renowned for their flexibility; however, with increased size, structural stiffness generally increases as well. For a 3,000m suspended span, the primary stiffness issue is ensuring adequate aeroelastic stability. Weight reduction will reduce system stiffness, but it is recommended that the design development overlook this factor. Once the most cost-efficient (low weight) concept is identified, various methods can address wind stability if it proves insufficient. For a twin-box deck, increasing the distance between the two boxes will raise the critical wind speed at a relatively moderate additional cost.

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