Assessment of bridge lifetime in fatigue against abnormal loads. Case of Normandy bridge

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ASSESSMENT OF BRIDGE LIFETIME IN FATIGUE AGAINST ABNORMAL LOADS. CASE OF NORMANDY BRIDGE.

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ABSTRACT

Some ageing bridges exposed to heavy traffic loads or abnormal loads may have critical details, either against extreme loads or in fatigue. Old bridges were designed with design codes and load models which are now exceeded by the authorized vehicle loads. Therefore, keeping the bridge safety and reliability at an acceptable level requires periodical reassessments of some structural parts, using updated traffic data, e.g. weigh-in-motion (WIM) data.

For extreme loads and current ultimate limit states, extrapolated maximum axle, vehicle or total loads, depending on the considered effect and influence line length, are used to assess the maximum load effects which may be exceeded with a given probability. They are compared to the design loads affected of the partial safety factors. For fatigue limit state and lifetime assessment, the updated traffic loads, if available, or some estimation based on similar traffic flow, are used to calculate expected lifetime with the Miner's law and fatigue resistance (S-N) curves. These lifetimes are compared to the required ones, taking into account the elapsed bridge lifetime.

In several country, like in France, abnormal loads regulation was made more flexible in order to avoid long administrative delay to get the permits, and up to some gross vehicle weight limits, the permit can be obtained very easily and quickly on-line through Internet. Some routes are allowed to different classes (1 to 3 in France) of abnormal loads, up to 120 t. Before labelling a route for a given class, all the sensitive bridges should be checked. In 2017, the prefect of Normandy asked to open the bridge of Normandy to the class 3 abnormal loads (120 t). The bridge concessionaire and the Ministry of Transport appointed IFSTTAR and a consulting company (Quadric) to perform some assessment of the impact of these abnormal loads on the bridge orthotropic deck lifetime in fatigue.

The paper will present some of the sensitive bridges and details, a quick review of abnormal loads or load models, the trend of heavy vehicle weight limits in the EU, and then the impact of these loads on existing bridges. A special focus will be done on the study carried out for the fatigue of Normandy bridge under current and abnormal traffic loads, and how the abnormal loads can reduce the bridge lifetime. These results are useful for the decision makers to take the final decision on abnormal load authorization.

1. CONTEXT AND PROBLEM STATEMENT

There are three bridges crossing the Seine river between the city of Rouen and Le Havre (located at the Seine’s mouth), over 100 km. The suspended bridge of Tancarville, located 30 km upstream of Le Havre, with a total length of 1,420 m and a main span length of 608 m, was opened in 1959. The suspension cables were replaced in 1996-99 because of the corrosion. The bridge of Brotonne, located 50 km upstream of Le Havre, is a cable-stayed bridge of 1,278 m in length, with a main span of 320 m. It opened in 1977, but the truck traffic is now restricted because of health problems. The bridge of Normandy is the latest built near to Le Havre, and opened in 1995. It is a cable-stayed bridge with a main span of 856 m in length and a total length of 2,141 m. Until now, none of these three bridges is open to abnormal loads, i.e. gross vehicle mass (GVM) exceeding the National (and European) legal limits, of 44 tons (40 tons in the European Union, EU). However, the port of Le Havre is the second busiest in France with 67 million tons of freight and 2.6 million twenty-foot equivalent units (TEU) per year. Thus, a large number of heavy vehicles cross the Seine River to access to or to leave from the port, some of them carrying indivisible abnormal loads. Under the current regulation, these abnormal loads have to make a long detour of app. 200 km, through the city of Rouen, and to cross the city downtown. Therefore, the prefect of Normandy asked to the Chamber of Commerce of the Seine Estuary (CCISE), concessionary of the bridge of Normandy, to investigate the feasibility and conditions of opening the bridge to abnormal loads up to 94, 96, 108 and 120 tons. The French Ministry of Transport, the conceding authority, supervises the study and the final decision of accepting or not accepting the abnormal loads. The concession contract ends in 2027, and by that time, the CCISE must return the bridge in a very good state to the French State.

The CCISE, acting as a responsible concessionary, first commissioned a consulting company (Quadric) to check the fatigue lifetime of the most sensitive and critical details, using the standardized fatigue load model (LM3) of the Eurocode EN1991-2 (CEN, 2003). The LM3 consists of two tandem axles. The centre to centre distance of the LM3 tandem axles is 7.2 m and each of the four axle loads weigh 120 kN. This model was found much too conservative for the bridge of Normandy, designed before the Eurocodes, and leads to unrealistic calculated lifetimes of a few years. Therefore, advised by Michel Virlogeux, the designer of the bridge (and of many other large bridges around the World), the CCISE commissioned in 2017 a study to the French Institute for Science and Technology of Transport, Planning and Networks (IFSTTAR). The proposed methodology was first to collect load data under the current traffic on the bridge, because only the traffic volume (truck flow by category) was known using the bridge tolling information. However, the truck and axle loads remained unknown. These data were compared to three other traffic load patterns measured on other French motorways. The next step consisted to re-assess the influence lines of the most sensitive details by FEM calculations (done by Quadric), and to compare them to those measured in 1995 during the initial study in fatigue of the bridge (Carracilli & Jacob, 1995). Then a simplified fatigue assessment and lifetime calculation were carried out using a simplified load model made of a standard tridem axle of 27 tons, the maximum allowed mass on a tridem according to the European Directive 96/53/EC (EC, 1996). A more realistic assessment was done using the current traffic loads measured on the bridge of Normandy and the lifetimes were compared with those calculated with the three other traffic patterns, and with the results of the initial study of 1995. Finally the superimposition of the expected abnormal loads and the current traffic loads led to new fatigue lifetime assessment to evaluate the additional damage and lifetime reduction due to the abnormal loads.

The main question was to check if two daily crossings of four defined abnormal loads would significantly reduce the expected fatigue lifetime of the bridge.

2. NORMANDY BRIDGE AND DETAILS SENSITIVE TO FATIGUE

2.1. Normandy bridge structure

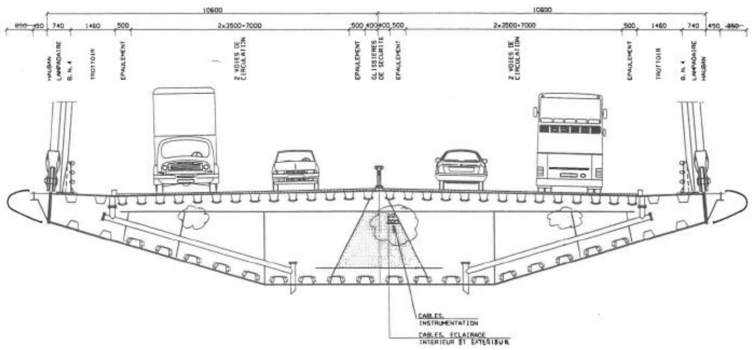
This exceptional bridge, built from 1989 until 1995, remained the longest cable-stayed bridge in the World until 2003. It crosses the Seine estuary between Le Havre and Honfleur (Figure 1a), and carries the four traffic lanes of the motorway A29, plus two cycling paths and two footpaths (Figure 1b). The main North-South traffic (Channel tunnel from UK, north of France and Benelux to Britanny and south west of France or Spain) crosses this bridge, as well as a significant part of the freight traffic to and from the port of Le Havre. However, the traffic Le Havre-Paris crosses the Seine River on the bridge of Tancarville (motorway A131).

(a)

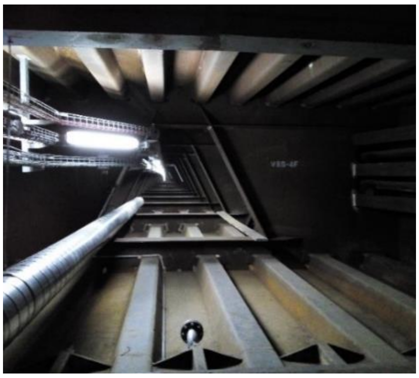
(b)

Figure 1 - Bridge of Normandy, (a) aerial view from the south, (b) view of the deck.

The two pylons of 215 m in height support a deck of 23.60 m in width with 184 cables, with lengths from 95 to 460 m. The main span of 856 m has a central part in steel of 624 m in length, and two parts of pre-stressed concrete (116 m from each pylon). The steel part is made of 32 segments of 19.65 m in length and 3.05 m in height, each supported by two cables, one on each side. The steel deck is an orthotropic box with trapezoidal longitudinal stiffeners spaced by 0.60 m and of 0.30 m in height (Figure 2). The cross beams (diaphragms) are spaced by 3.93 m. The access viaducts are of pre-stressed concrete.



(a)



(b)

Figure 2 - Bridge of Normandy: (a) cross section, (b) inside of the box.

The steel plate is 14 mm thick under most of the slow lanes and 12 mm thick under the fast lanes. The thickness of the stiffeners are respectively 7 and 6 mm. In the initial design, the thickness changed between the two traffic lanes, but a cycling path of 1.1 m in width was added afterwards, which shifted the left edge of the slow lane on the thinner part of the plate (Figure 3a).

2.2. Details sensitive to fatigue and influence lines

The most sensitive details in fatigue in an orthotropic deck under traffic loads are the welds between the upper deck plate and the lateral web of the longitudinal stiffeners, with a risk of crack propagation either in the deck plate or in the stiffener web (Figure 3b). These details are in the fatigue class 71 for a full weld penetration or in class 50 for a partial penetration, according to the Eurocode 1993-1-9 (CEN, 2005). For the study carried out in 1995, 35 strain gauges have been installed at the critical locations of two bridge sections (Figure 3c) to monitor the stresses induced by the traffic loads:

• under the stiffeners' bottom face at mid-span between two cross beams, to measure the longitudinal bending moment stresses (no fatigue effects): J3, 6, 11, 24, 25, 26, 27 and 28;

• under the upper deck plate to measure the transverse bending stresses: J2, 4, 5, 8, 9, 14, 15, 16 and a chain J17-23;

• outside the stiffeners' flanges just below the longitudinal welding: J7, 10 and 12.

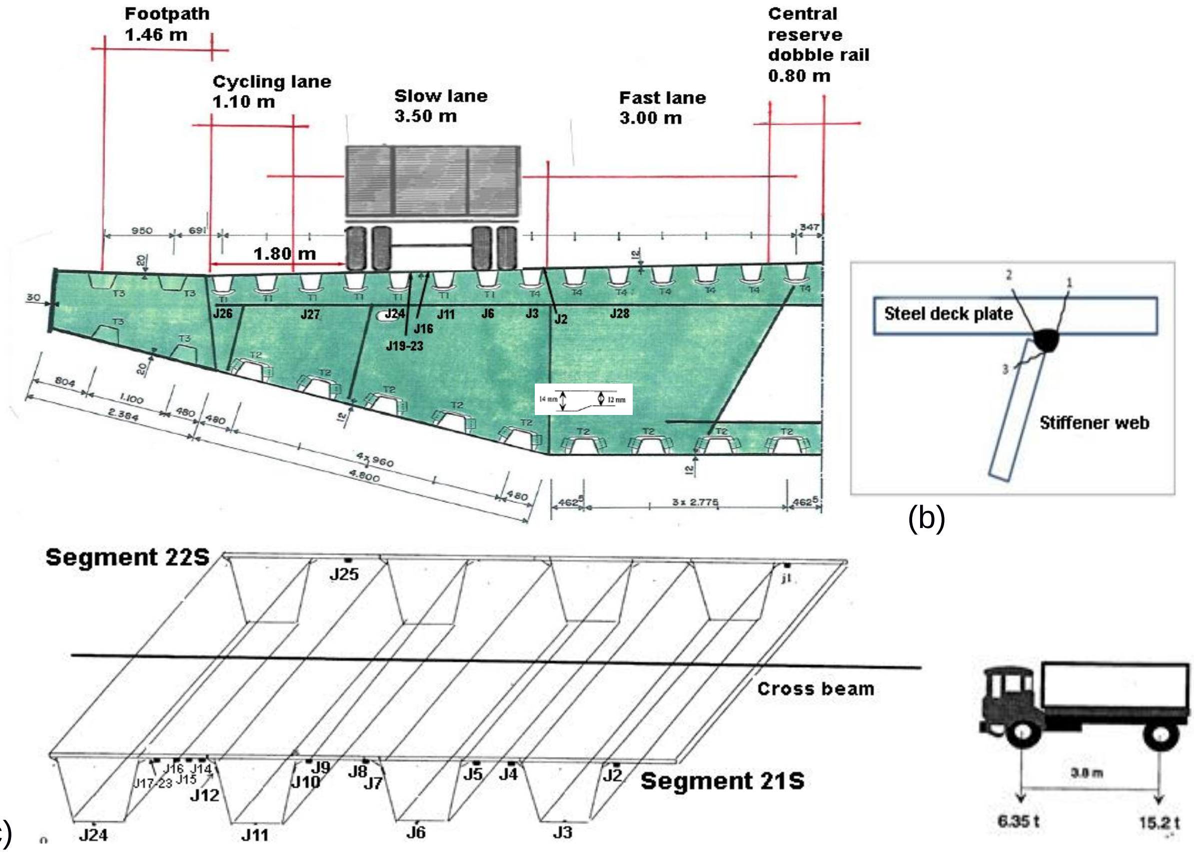


Figure 3 – (a) Bridge of Normandy, transverse cross section, (b) detail sensitive to fatigue, (c) stain gauges, and (d) test truck.

The influence lines (IL) corresponding to the stresses recorded by each strain gauge were measured in 1995 using a 2-axle rigid test truck (6.35 – 15.21 t) shown in Figure 3d. The second axle, supported by two twin wheels, was used to determine the influence lines. Figure 3a shows the transverse location of the truck in the slow lane. Figure 4 shows the influence lines of the three most sensitive details (J7, J10 and J12 for the stiffener flanges, and J8, J9 and J23 for the upper plate of the deck), which are used in the fatigue analysis. Most of these details are located near the left wheel path of the test truck. The gauges J7 and J8 are located under the 12 mm thick plate, while the gauges J9, J10, J12 and J23 are under the 14 mm thick plate.

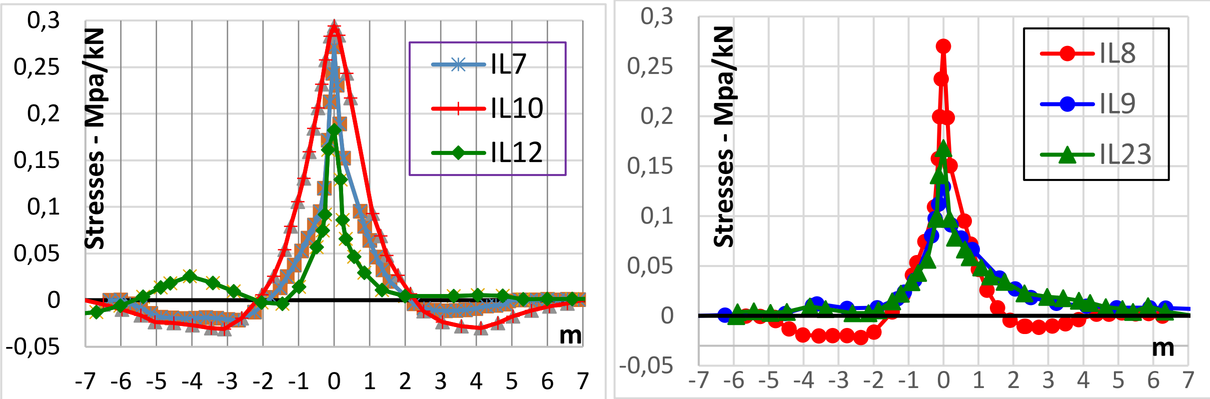


Figure 4 – Influence lines: stiffener flange (left), upper plate/deck (right)

3. TRAFFIC LOADS

Since the opening of the bridge of Normandy, the number of truck crossing the bridge every year raised from 200,000 to more than 1 million, for both directions (Figure 5a). The tolling data give accurate statistics of the truck number per category (number of axles), but do not provide any information about their loading. Thus, the CCISE was highly interested to collect traffic loads using a WIM system. However, it is not easy to find an appropriate location to install a road sensor WIM system. On the steel deck, the pavement is too thin to install WIM sensors and the risk of water intrusion is too high to allow that. On the concrete deck, the longitudinal slope is above the limits proposed by the European Specification of WIM by COST323 (Jacob et al., 2002). In addition, close to the toll area the trucks are accelerating or breaking, which does not comply with the WIM requirements.

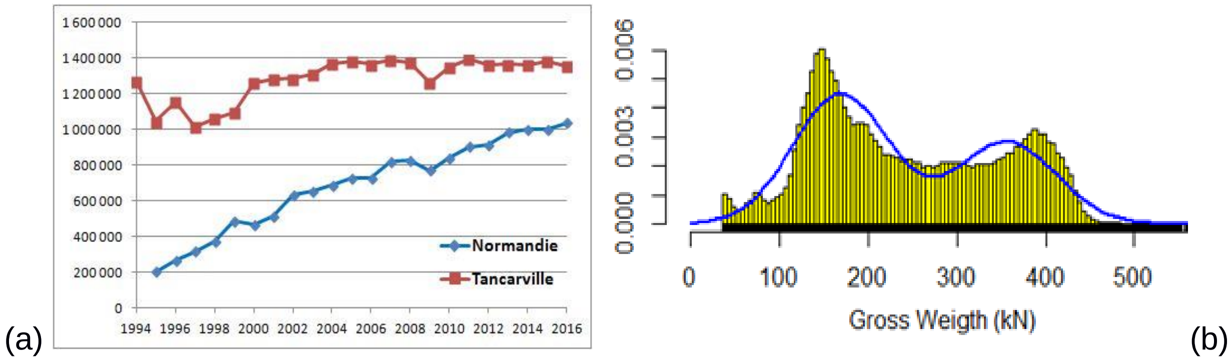
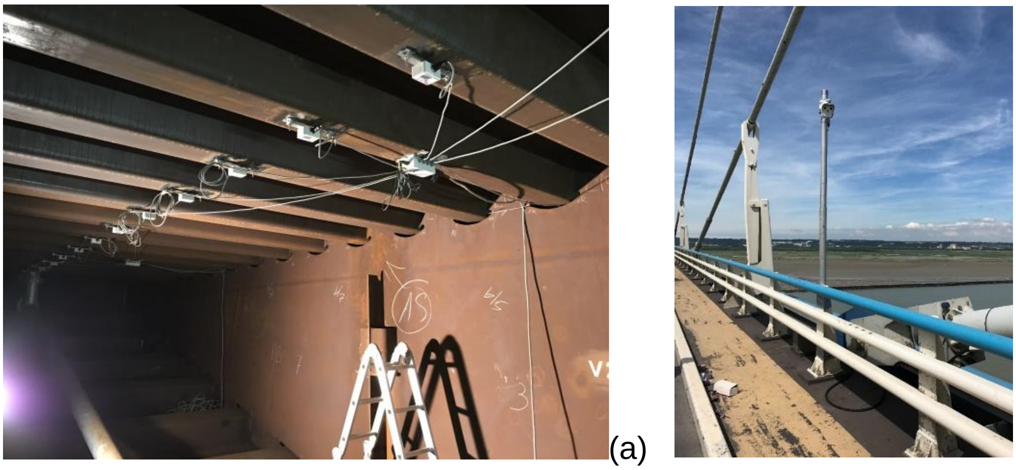


Figure 5 – Heavy traffic on the Normandy bridge: (a) truck flow evolution 1994-2016, (b) gross weight distribution (> 3.5 t)

3.1. On-site load measurements with a bridge-WIM system

In July 2017, IFSTTAR and Cerema installed a bridge WIM (B-WIM) system SiWIM, manufactured by the Slovenian company Cestel, under the traffic lanes in the south-north direction, in the segment 21, just north of the mid span of the bridge. This section was chosen because of the very low slope and the distance to the tollgate (located 2 km north, at the end of the bridge), which allows capturing the overloaded trucks during enforcement sessions. 14 extensometers were fixed under the lower face of the longitudinal stiffeners at mid-span between two cross beams, 7 under each traffic lanes (Figure 6a). They measure the strain induced by the bending of these stiffeners while wheels are crossing this bridge section, from which the axle and vehicle weights are derived (Dempsey et al. 1998, 2000). Four more extensometers installed beyond the upstream and downstream crossbeams measure the vehicle velocities and launch the strain record when a vehicle is approaching.

A camera mounted on a mast along the right traffic lane on the bridge deck, records the truck pictures and license plates if overloaded (Figure 6b).



(a) (b)

Figure 6 – SiWIM in the Normandy bridge: (a) extensometers under the longitudinal stiffeners in the box, (b) camera on the bridge deck

25 runs of a fully loaded (42.39 t) 5-axle articulated truck (T2S3) allowed calibrating the system, among them 4 were eliminated because of doubtful values and large gross weight errors. The accuracy of the SiWIM, assessed using the COST323 Specs (Jacob et al., 2002) was not good (Table 1), above all for the single axles and because of a very high and unexpected scattering of the axle loads. An accuracy check done on August 2, with 36 vehicles from the traffic flow, weighed in static after the tollgate on an approved axle scale, confirmed an accuracy in class E(35) for the gross weights and groups of axles, and in E(50) for the single axles. For the 5 axle-articulated (T2S3), and after recalibration, the accuracy was E(30), E(30) and E(40) for the 3 criteria. Again, the axle loads are highly scattered, for an unknown reason. The accuracy on Millau bridge, another orthotropic deck cable stayed bridge, instrumented in 2009 was better (Jacob et al., 2010), and even improved in 2016 after the installation of a new SiWIM, almost in class B(10) (Schmidt et al., 2016). In addition, here it was necessary asking to ZAG (Slovenia) to revise twice the SiWIM parameter settings, because initially many aberrant values were generated, e.g. axles with no load or abnormal heavy loads, etc.

Table 1 – Accuracy of the SiWIM (Calibration test, conditions R1/I), vs COST323.

	n	m (%)	s (%)	δ_{min} (%)	Class
Gross weight	21	0.24	6.33	18.0	D(25)
Group of axles	63	-2.61	4.04	12.9	C(15)
Single axles	42	5.35	14.76	42.9	E(50)

The SiWIM recorded the traffic across the bridge from July 2017 until January 2018 for this study, and even more, until May 2018 after it. 237,584 truck above 3.5 t were recorded over 7 months, and 224,354 (94.4%) were kept after cleaning the file and removing the aberrant vehicles. 61% of the trucks are 5-axle, then 18% are 4-axle and 13% 2-axle. There are 5% of 3-axle and 3% of more than 5 axles vehicles. Figure 5b gives the gross vehicle mass bimodal distribution of the trucks (above 3.5 t). The first mode, centered at 166 kN, mainly contains 2- an 3-axle vehicles and unloaded or half-loaded 5-axle vehicles, while the second mode, centered at 350 kN, contains 4-, 5- and 6+ axle vehicles, fully loaded.

3.2. Traffic loads used for fatigue assessment

The traffic measured on the Normandy bridge is conservative to assess the fatigue of the bridge details over the past 24 years of operation, because of the continuous increase of the traffic flow (Figure 5a). However, in the future the traffic may still increase, in both volume and loads. Therefore, the lifetimes of the most critical details are calculated if exposed to three other traffics recorded on two other motorways (A20 and A9) and a main highway (RN4). Table 2 reports the relevant statistics of these traffics.

Table 2 – Traffics of French motorways and highways for fatigue assessment.

Site	Dates	Nb days	Nb trucks	Mean flow trucks/day	Proportion 2nd mode	Median 2nd mode (kN)	St. Dev. 2nd mode (kN)
Normandy (A29)	7/17-1/18	189	224354	1187	40%	350	50
Massay (A20)	2015	362	498269	1376	20%	384	27
Maulan (RN4)	2015	353	755757	2141	28%	383	30
Fabrègues (A9)	1-6/2015	189	901231	4768	40%	371	26

The traffic measured on the A20 in the center of France (Vierzon to Limoges) has the closest statistics to the A29 traffic on the Normandy bridge, with slightly higher loads in the 2nd mode of the gross vehicle weights, but a lower proportion of trucks in it. The traffic on the RN4 (highway Paris-Nancy) is the second closest one, but with a 80% higher volume of trucks. The traffic of the A9 motorway near Montpellier (Lyon and Marseille to Barcelona) is one of the heaviest in France and much more aggressive than the A29. It gives an upper bound of the fatigue damage, but much too conservative. All these traffics were measured over 6 to 12 months in 2015, with several hundreds of thousends trucks.

3.3. Abnormal loads

Four abnormal vehicles (Figure 7) were considered as representatives of the potential very heavy loads, which could cross the bridge of Normandy if allowed:
• two cranes G1 and G2 of 96 and 108 tons, with 8 and 9 axles, all loaded at 12 tons;
• two conventional abnormal 8-axle vehicles C1 (94 tons) and C2 (120 tons).
Most of the wheels of these vehicles are equipped with extra wide tyres, e.g. 0.37 m in width. The vehicles C1 and C2 have a group of 5 close axles (1.55 m spacing) loaded at 12.8 and 17.5 tons, but each axle comprises 8 wheels (4 twin wheels).

The vehicles C1 and C2 have the same geometry. They consist of a single front axle of 6 or 7 t with single tires, a tandem axle (2x12 t or 2x12,75 t) with dual tires, and a series of 5 axles, spaced by 1.55 m, loaded at 12.8 t or 17.5 t, with 4 twin tires each (i.e. 8 wheels per axle). The tires of the 3 first axles are 0.37 m in width.

The future number of abnormal load crossings are assumed as 2 crossings of each (G1, G2, C1 and C2) per day and direction but the week-ends, i.e. 600 crossing of each per year. This assumption is conservative, in order to make a safe estimation of the expected lifetimes.

4. FATIGUE ASSESSMENT

4.1. Stress cycle calculation

The CASTOR-POLLUX software (Schmidt and Jacob, 2010) calculates the stress variations under the four traffics presented in the section 3.2, for the given influence lines given in the section 2.2. It counts the stress cycles using the rain-flow method and store the results in histograms. The fatigue lifetimes are assessed with the Miner's law, assuming a stationary traffic all along the lifetime, and knowing that the details are in class 70 for good welds according to the Eurocode 1993-2 (Steel bridges). However, the class 50 is checked in case of defective welds. The traffic stationarity assumption is quite conservative according to the low traffic on the bridge during the first years of operation, but a future increase of the traffic flow or loads may compensated that

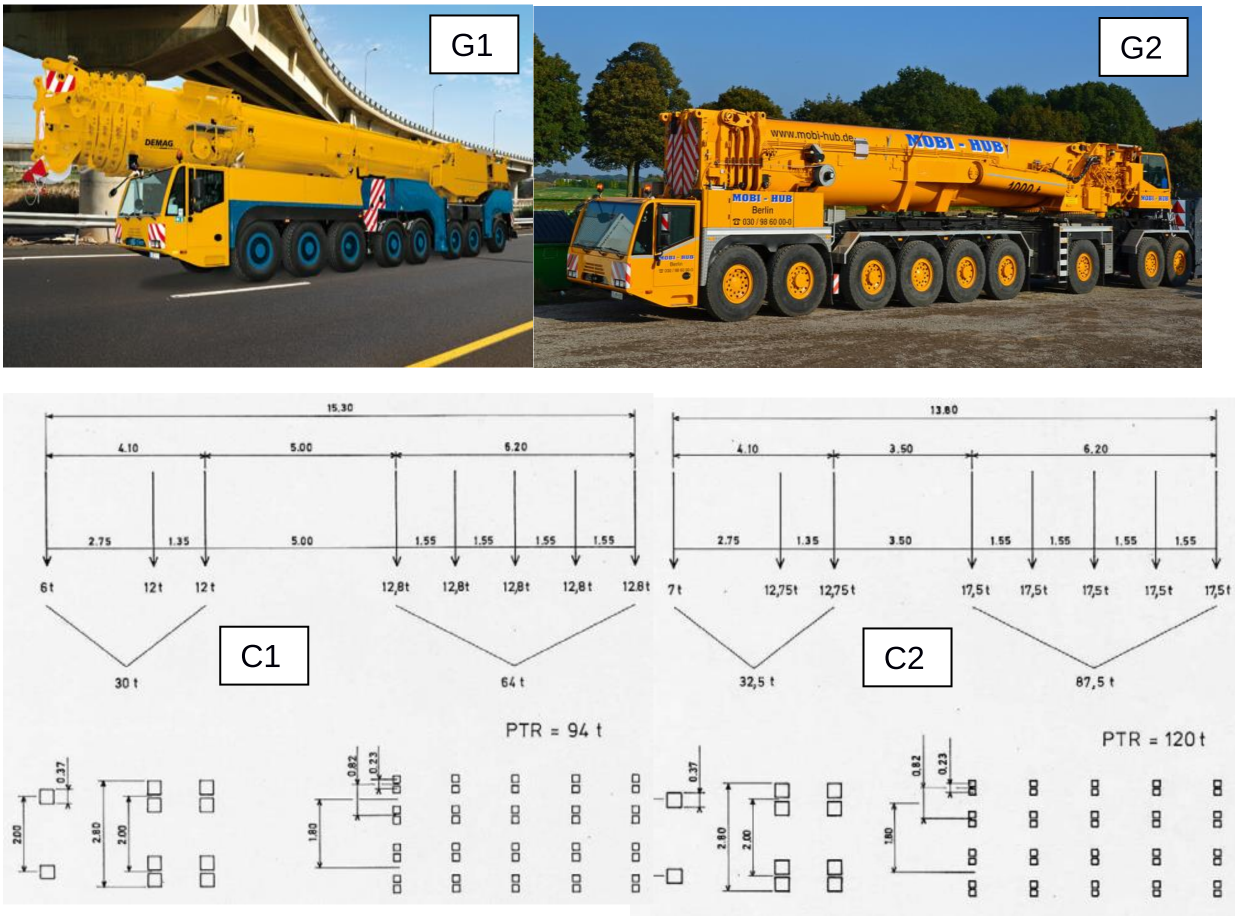


Figure 7 – Abnormal loads: (G1) (G2) cranes 98 t - 108 t, (C1) (C2) vehicles 94 t - 120 t

For the abnormal loads, each crossing induces a limited number of stress cycles. Each crane G1 and G2 induces 4 cycles, one per single axle or group of axles. Because of the short lengths of the influence lines (local effects), when the spacing between two axles exceeds 2 m, two independent cycles are considered. Reversely, according to the influence line shape, each group of axles (internal spacing below 1.65 m) induces a single stress cycle. Similarly, the C1 and C2 vehicles induce each 3 cycles, for the single axle, the tandem and the group of 5 axles. However, the cycle due to the front axle never exceed the truncation threshold of the fatigue S-N curves of the classes 50 and 71, resp. 20.2 and 28.7 MPa, and thus are ignored. Table 3 gives all the stress cycles induced by these abnormal vehicles.

Table 3 – Stress cycles induced by each abnormal vehicle on the 6 influence lines.

Influence line	Stress cycles (rain-flow) in MPa			
	Crane G1	Crane G2	Vehicle C1	Vehicle C2
IL J7	36.5 – 2 x 34.8 – 32.0	34.9 – 3 x 34.8	36.6 – 39.1	38.9 – 53.5
IL J10	45.3 – 2 x 40.2 – 34.6	42.4 – 3 x 40.2	42.7 – 48.2	45.4 – 66.0
IL J12	22.9 – 2 x 22.5 – 21.5	21.9 – 3 x 22.5	23.1 – 24.5	24.5 – 33.6
IL J8	33.0 – 2 x 32.8 – 31.8	32.3 – 3 x 32.8	34.7 – 35.7	36.9 – 48.7
IL J9	21.7 – 2 x 20.1 – 15.2	20.8 – 3 x 20.1	22.4 – 23.2	23.8 – 31.8
IL J23	25.8 – 2 x 24.2 – 19.8	25.2 – 3 x 24.2	24.9 – 27.8	26.4 – 38.1

4.2. Lifetime calculation under the four traffics

Table 4 gives the lifetimes calculated for the 6 influence lines, IL 7, 10 and 12 (stiffener flanges) and IL8, 9 and 23 (upper plate), under the four traffics and for the two fatigue classes. A comparison with the IL 8 and the results of the calculation done in 1995 with the traffic measured on the bridge of Tancarville, shows consistent conclusion: the lifetimes were resp. 136 and 565 years in fatigue classes 50 and 71, instead of 62 and 586 with the current traffic of the Normandy bridge (A29).

Table 4 – Lifetimes (in years) calculated for each traffic and influence line.

	Class 50				Class 71			
Traffic	A29	A20	RN4	A9	A29	A20	RN4	A9
IL J7	32	29	24	7	254	296	274	75
IL J10	11	7	6	2	57	40	33	10
IL J12	691	237	131	43	61279	35145	13445	4426
IL J8	62	46	45	10	586	588	573	113
IL J9	22173	-	8644	1469	∞	∞	∞	∞
IL J23	1141	-	614	102	208381	-	755054	95738

For the current traffic (A29), in class 71 the details are well designed and the lifetimes acceptable, except may be for the IL 10 which gives a bit too short lifetime. The results are quite close for the two other traffics of A20 and RN4. However, the bridge of Normandy is not designed to support a very heavy and dense traffic such as of the A9 motorway.

4.3. Lifetime reduction with the abnormal loads

The abnormal loads may only affect the lifetimes of the most sensitive details, i.e. IL 7, 8 and 10, while for the 3 other details, the safety margin is very high. First, the individual impacts of the abnormal vehicles G1, G2, C1 and C2 are assessed. Using the stress cycles (Table 3), the Miner's law and the S-N curves of each fatigue class, the maximum number of crossings of each abnormal vehicle are calculated (first line in each cell of Table 5). Then dividing these numbers by 600 (number of crossings assumed per year), the lifetimes under each abnormal vehicle alone are calculated (second line in each cell of Table 5). Equations (1) and (2) give the relative lifetime reduction *r* due to one abnormal vehicle crossing the bridge 600 times per year:

$$\frac{1}{T} = \frac{1}{T_1} + \frac{1}{T_2} \qquad (1)$$

$$r = \frac{T_1 - T}{T_1} = \frac{T_1}{T_1 + T_2} \qquad (2)$$

where T_1 and T_2 are the lifetimes under the A29 traffic loads (Table 4) and under the abnormal vehicle alone (Table 5, second line of each cell), T is the resulting lifetime. The values of *r* (in %) are given in Table 5 (third line of each cell). The lifetimes T_1 and T_2 are both slightly under-estimated, because the traffic increased quickly since the bridge opening and no abnormal loads crossed the bridge since that time. Therefore, the ratio *r* should be quite realistic.

The contributions of each abnormal vehicle G1, G2 and C1 to the total damage in fatigue and thus to the lifetime reduction remain below 2.6%, but for the vehicle C2 for which this rate reaches 5.3% (for the longest lifetime). These values are very limited with respect to the uncertainties of the Miner's law and fatigue calculation. Moreover, the effects of the abnormal vehicles C1 and C2 are overestimated, because they have wide twin tires on the tandem axles (2 x 0.37 m instead of 2 x 0,24 m for common dual tires), and above all 8 wheels on the 5-axle group. Thus, the higher transversally spread of the loads significantly reduces the stress intensity in the stiffeners and upper plate. The influence lines used where measured for standard twin tire axle. The influence lines adapted to such wide tires or multiple wheel axle would be flatter, and thus would reduce the calculate fatigue damage.

Table 5 – Effect in fatigue of the abnormal vehicles (one by one).

Influence line	Crane G1		Crane G2		Vehicle C1		Vehicle C2	
	Class 50	Class 71	Class 50	Class 71	Class 50	Class 71	Class 50	Class 71
IL J7	1.693 2 823 1.12%	9.778 16 296 1.53%	1.650 2 751 1.15%	9.530 15 883 1.57%	2.495 4 158 0.76%	13.754 22 923 1.10%	1.253 2 088 1.51%	4.124 6 873 3.56%
IL J10	0.963 1 606 0.68%	4.349 7 248 0.78%	0.924 1 540 0.71%	4.348 7 247 0.78%	1.394 2 323 0.47%	5.354 8 923 0.63%	0.697 1 161 0.94%	2.140 3 567 1.57%
IL J8	2.293 3 821 1.60%	13.238 22 063 2.59%	2.276 3 793 1.61%	13.140 21 900 2.61%	3.460 5 766 1.06%	19.976 33 293 1.73%	1.561 2 689 2.25%	6.280 10 467 5.30%

In each cell: first line = number of crossings allowed (in millions), second line = lifetime under the single abnormal vehicle (600 runs per year), third line = percentage of the lifetime under the A29 traffic.

Table 6 gives the lifetimes of the 3 details exposed to 600 runs of each of the 4 abnormal vehicles for each fatigue class, compared to the lifetimes under the A29 traffic, and then the final lifetime if adding both (A29 traffic and 4 abnormal loads). The ratio *r* indicates the lifetime reduction (in %) due to the 4 abnormal loads. For the longest lifetime, the reduction reaches 11.3% but the lifetime remain very safe. For the shortest lifetimes, the reduction rate is limited around 3-4%.

Table 6 – Global effects and lifetime reductions under the four abnormal vehicles.

	Class 50				Class 71			
	A29	4 abn. veh.	Final	r	A29	4 abn. veh.	Final	r
IL J7	32	696	31	4.40%	254	3190	235	7.37%
IL J10	11	390	10.7	2.74%	57	1496	55	3.67%
IL J8	62	934	58	6.22%	586	4618	520	11.3%

5. CONCLUSIONS

The study allowed assessing the real traffic loads on the bridge of Normandy, in the south-north direction. The traffic data, recorded by a bridge WIM system over more than 7 months, combined with the influence lines measured in 1995 provided an estimation of the lifetime of the most sensitive details in fatigue, i.e. the welds between the longitudinal stiffeners and the upper deck plate. These lifetimes are in good agreement with the initial estimation made in 1995 with the traffic of the Tancarville bridge, and consistent with those obtained under similar traffic data recorded on other highways and motorways.

An estimate of the fatigue damage induced by four abnormal vehicles of 94 to 120 t, under conservative assumptions on their potential frequencies and tire imprints, revealed that such abnormal loads would not reduce the lifetimes by more than 5 to 10%. Thus, allowing abnormal loads up to 120 t on the Normandy bridge seems feasible without too much risk of cracking in fatigue. Calculating the influence lines adapted to very wide tires and multiple wheel axles, would allow assessing more accurately the stress cycles induced by these abnormal vehicles, and would reduce the impact of these abnormal loads. The transverse scattering of the wheel (path) location would also reduce the fatigue damage if properly measured and taken into account.

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