The Crane Industry Council of Australia ABN 73 002 565 773
PO Box 136, Mount Waverley, Victoria 3149 • Unit 10, 18-22 Lexia Place, Mulgrave, Victoria 3170
Telephone: 03 9501 0078 • Facsimile: 03 9501 0083
Email: admin@cica.com.au • Website: www.cica.com.au

Lifting Industry Standards

Hydro-pneumatic Suspension Impact on Bridge Dynamic Load Factors

Purpose:

Since the mid-eighties All-Terrain cranes have been equipped with hydro-pneumatic suspension systems. The designed axle load of these cranes in a transport configuration is 12 metric tonnes per axle (Static Load). Several studies have been completed to show the impact of the hydro-pneumatic suspension advancement over conventional mechanical spring and air spring suspensions. This paper provides an executive summary of some of the relevant documents that describe the benefits of using the most advanced mass production suspension technology – hydro-pneumatic suspensions.

Current bridge dynamic load factors do not take into account the improved dynamic response that is provided by hydro-pneumatic suspensions. Heavy vehicles have factors as shown in Table 1 below. Bridge capacity is based on three inputs:

1. Static Load – axle weight at rest / not moving
2. Dynamic Factor – the effectiveness of the suspension and the impact of speed on the structure
3. Load Factor – load frequency and load certainty (i.e. risk of loads being more than specified)

$$Bridge\ Capacity\ = Static\ Load\ \times Dynamic\ Factor\ \times Load\ Factor$$

Or

$$Static\ Load\ = \frac{Bridge\ Capacity}{Dynamic\ Factor\ \times Load\ Factor}$$

For pre-existing bridges, where bridge capacity is already defined, decreasing the dynamic factor and / or the load factor will increase the allowable static load, i.e. axle load.

Table 1: Current Bridge Design Load Factors[1]

Vehicle Type	Dynamic Factor	Load Factor	Suspension Type
Standard Semi Trailers	1.4	2.0	Mechanical or Air Spring
Heavy Platform Low-Bed Trailers w/ Speed Restrictions	1.1	1.5	Hydro-pneumatic
Cranes	1.3	1.8	Hydro-pneumatic

Examples of the three types of suspensions are shown in Figure 1.

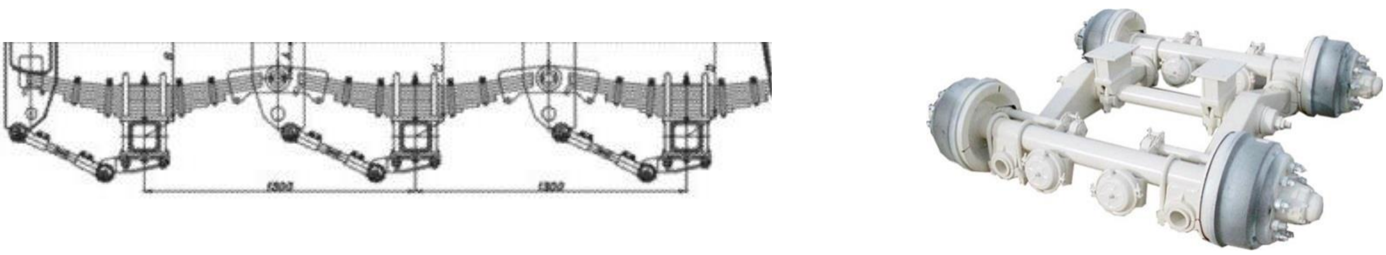

Figure 1a: Mechanical Spring / Walking Beam

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Figure 1b: Air Spring

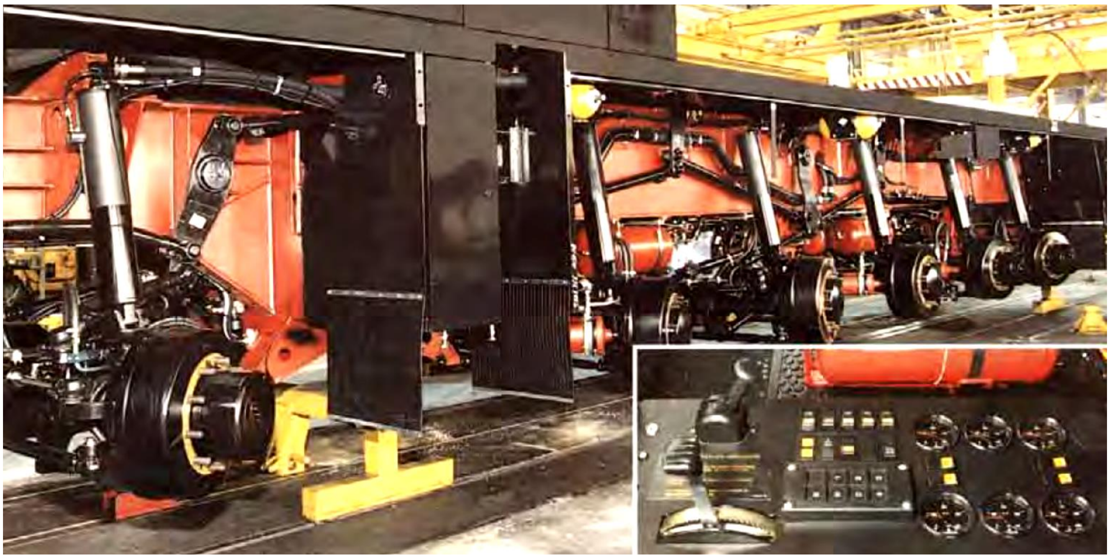

Figure 1c: Hydro-pneumatic

Dynamic Factor

The dynamic factor is based on the effectiveness of the vehicle suspension and the impact speed of travel has on the bridge structure. Several studies have been completed, both theoretical and physical to show the impact of different suspension types on bridge stress and displacement.

Theoretical

Theoretical analysis can show the idealised comparison between the different suspension types. Using computer models environmental noise factors do not skew the results. Examples of noise factors include, but are not limited to: tyre variation, variation in the path travelled, variation in speed travelled, heat effects throughout the test, and suspension variability from manufacturing tolerances.

Study: University of California at Davis[2]
Date: 30/6/2002
Summary: The model represents mobile cranes in four suspension configurations – walking beam (mechanical) suspension, steel leaf, air spring, and hydro-pneumatic suspension. The model simulates the dynamic road loads generated by mobile cranes. The results show that modern cranes with hydro-

pneumatic suspensions generate "significantly lower dynamic loads" than mechanical suspensions. The findings from the simulation leads to a recommendation to regulate axle load limits in a manner that compensates for different suspension systems.

The simulation starts with a basic vehicle dynamics model known as a quarter car model. This model only takes into account the suspension system on a single wheel. The difference in dynamic load for various suspension types is shown in Figure 2.

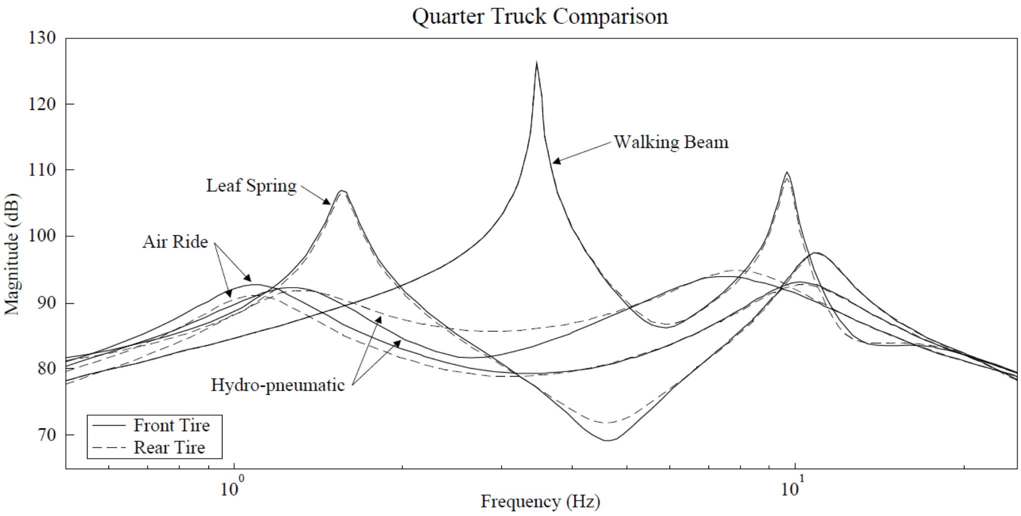

Figure 2: Dynamic Load Response

The results from the simulation show the overall benefit of hydro-pneumatic suspension over the same profile and axle loading.

<u>Practical</u>
Several studies have been completed nationally and internationally since the mid-80s to better understand the impact of hydro-pneumatic suspensions on road / bridge loads. These studies involved physical measurement of bridge deflection / strain with various suspension types and axle loads. The practical studies support the theoretical findings regarding the benefits of hydro-pneumatic suspensions over more traditional suspensions.

Where the theoretical study filtered all external noise factors to isolate the "pure" assessment of hydro-pneumatic suspension compared to other suspension types, the practical testing includes all variability and noise factors that occur in every day operation over bridge and road assets. The same variables that were filtered out of the theoretical study are now taken into consideration with the test measurements. The introduction of variability also shows further benefit of hydro-pneumatic suspensions as this suspension type is independent of road speed and road profile compared to more traditional suspension technology.

- Study #2: The Stress on a Bridge by Heavy Vehicles with Different Axle Suspension[3]
  Date: February 1987
  Summary: Three vehicles were tested over bridges to determine the deflections on bridges. The three vehicles were a 5-axle crane with hydro-pneumatic suspension, a 5-axle crane with leaf spring suspension, and a 3-axle truck. The axle spacing and loading is shown in Figure 3. The dynamic impact of the three vehicles was compared to the assumed stress requirements defined by DIN 1072.

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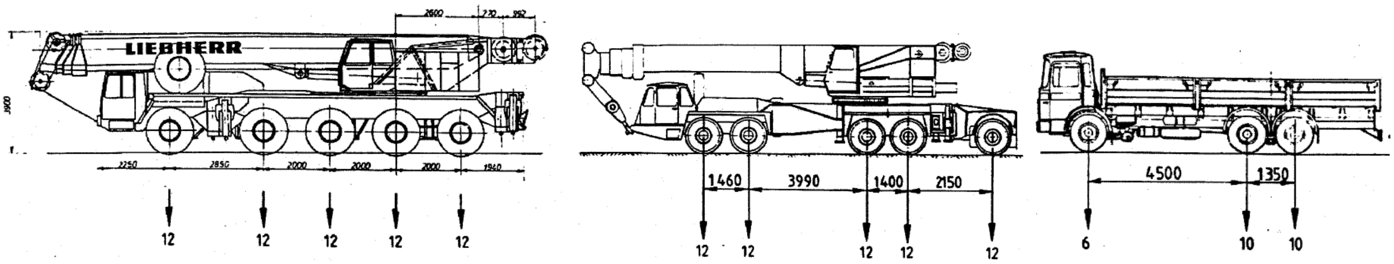

Figure 3: Test Vehicle Configurations

Two road profiles were used. The first was a smooth level road with negligible vertical discontinuities. The second was the same road with a 23mm steel plate added to induce the maximum bridge excitation. The results shown in Table 2 are dynamic deflection as a percentage change in static deflection. These percentages are equivalent to the dynamic factors used in the bridge capacity formula.

Table 2: Dynamic deflection for each suspension on smooth and step input

Vehicle / Suspension	Smooth Roadway	23mm step, 1m long
Crane / Hydro-pneumatic	10-15%	10-15%
Crane / Mechanical	Not reported	20-30%
Truck / Mechanical	40-50%	40-100%

It should be noted that the hydro-pneumatic suspension showed no increase in bridge deflection when the 23mm step was added. This shows the superior damping that the system provides. The dynamic changes from the crane with the mechanical suspension represent what the current dynamic factor is for all cranes, refer to Table 1.

The study concludes with the following comment:

“In summary it can be said that the static and dynamic load of bridges by hydro-pneumatic suspended vehicles is under the load specification required in DIN 1072. From a static structural point of view no restrictions for driving on bridges are therefore required.”

- Study #3: Hydro-Pneumatic Crane and Tractor Semi-Trailers: A Comparative Study of Their Dynamic Effects on a Short-Span Bridge[4]
  Date: 1997
  Summary: Similar to study #2, this Australian study completed by Dr. Rob Heywood for the National Road Transport Commission set out to review the impact of three different suspension systems on bridges. The three suspension systems where a crane with hydro-pneumatic suspension (AC205), a tractor- trailer with air suspension (BA), and a tractor-trailer with mechanical spring suspension (BS). Evaluations were made on both smooth road and with a 25mm x 300mm plank. One significant difference from Study #2 is that tests were completed over a wider speed range, up to 80kph. Figure 4 shows the dynamic increment (dynamic factor) for maximum deflection and strain on a smooth road. Figure 5 shows the same results when the plank was added.

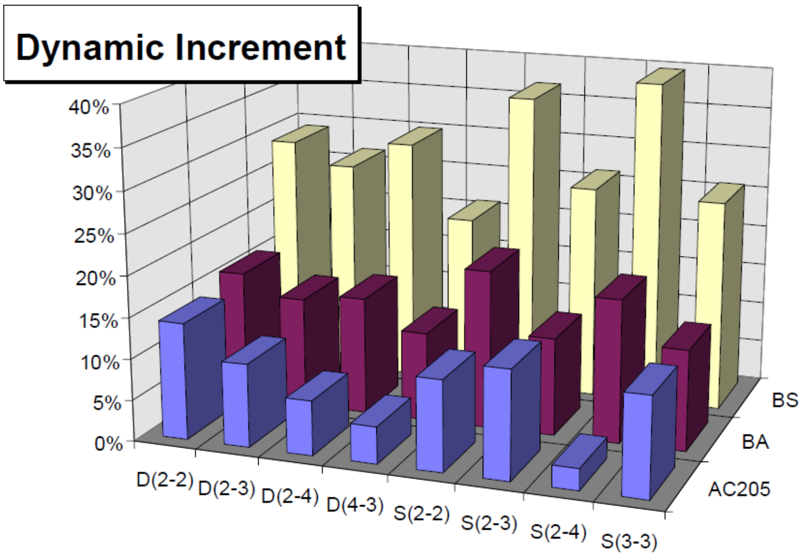

Figure 4: Maximum Dynamic Increment over Smooth Road

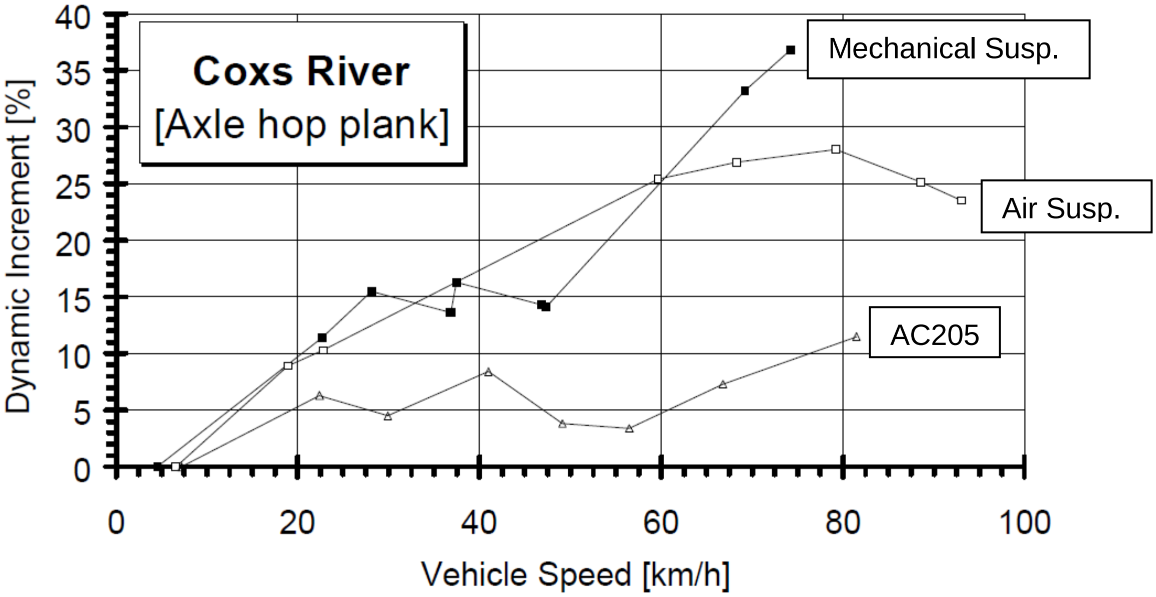

Figure 5: Dynamic Load Factor on Rough Road

The results show that the hydro-pneumatic suspension will be equivalent or better than that of air suspended vehicles. This would support the argument that the Dynamic Factor for hydro-pneumatic cranes should be more than 50% smaller than the Dynamic Factor for Standard Semi-Trailers. For the Coxs River Bridge, the hydro-pneumatic suspension induces only 10% of the dynamic loads where the tractor-trailer with mechanical suspension induced 40% and 25% for the tractor-trailer with air suspension. Further improvement was shown when the plank was added to simulate road roughness.

Load Factor

Load factor was not discussed in any of the research papers. All testing was completed at maximum static weight. Cranes are not divisible loads. The configuration is set by the manufacturer to travel at known axle weights. Figure 6 and 7 show the crane configurations as specified by different manufacturers.

Achse · Axle Essieu · Asse Eje · Мосты	1	2	3	4	Gesamtgewicht · Total weight t Poids total · Peso totale t Peso total · Общий вес, т
t	12	12	12	12	48[1)]

[1)] mit 10,7 t Ballast und Klappspitze · with 10.7 t counterweight and folding jib · avec contrepoids 10,7 t et fléchette pliante
con contrappeso di 10,7 t e falcone ribaltabile · con 10,7 t de contrapeso y plumin lateral · с противовесом 10,7 т и с удлинителем стрелы

Figure 6: Crane Configuration for Desired Axle Weights - 10.7T counterweight and fly jib

	Total						
12,0 t	48 t	8 x 8 x 8	445/95R25	6,3-0-18	8,0 t	–	–
12,0 t	48 t	8 x 8 x 8	445/95R25	50-3-18	7,5 t*	–	400 kg
12,0 t	48 t	8 x 8 x 8	445/95R25	6,3-0-18	6,8 t	17 m	–

Figure 7: Various Crane Configurations for Desired Axle Weight

When road registration is completed the axle weights are measured and the crane configuration is noted on the registration. Therefore, the load factor can be reduced.

Road usage should also be considered in calculating the impact of bridge fatigue. Over the past 10 years the crane industry's self-regulatory program, Crane**Safe**, has collected annual mileage accumulation for various cranes. This data is based on a population size in excess of 30,000 samples throughout the country. Figure 8 graphically shows kilometres travelled for different All Terrain cranes.

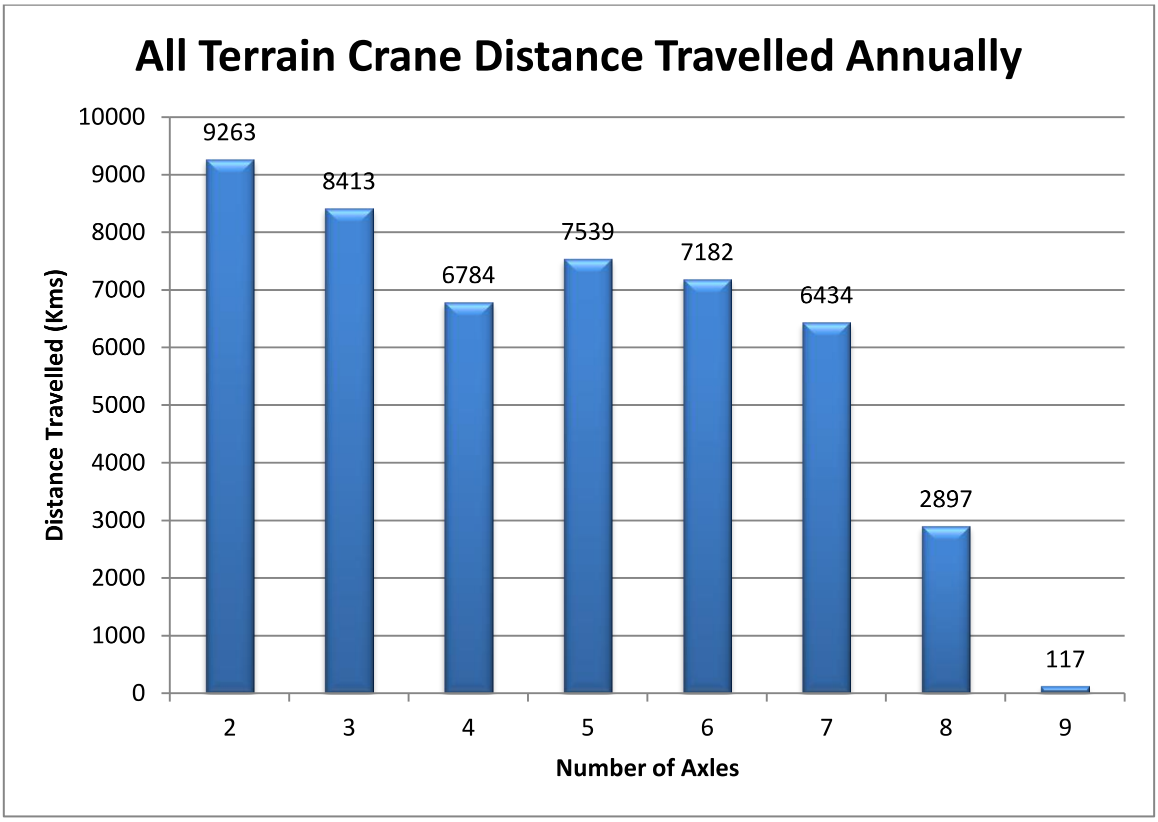

Figure 8: National Average of All Terrain Crane Distance Travelled

For all axle variants of All Terrain cranes the average distance travelled annually is 6078km. Compare this to the average distance travelled by articulated trucks of 83,000kms.[5] Freight carrying vehicles travelled 60 Trillion kilometers, of which articulated trucks travelled 7.4 Trillion kilometers.[5] Comparatively, All Terrain cranes travelled 8.4 Million kilometers. Articulated trucks travelled 880% more kilometers than All Terrain cranes.

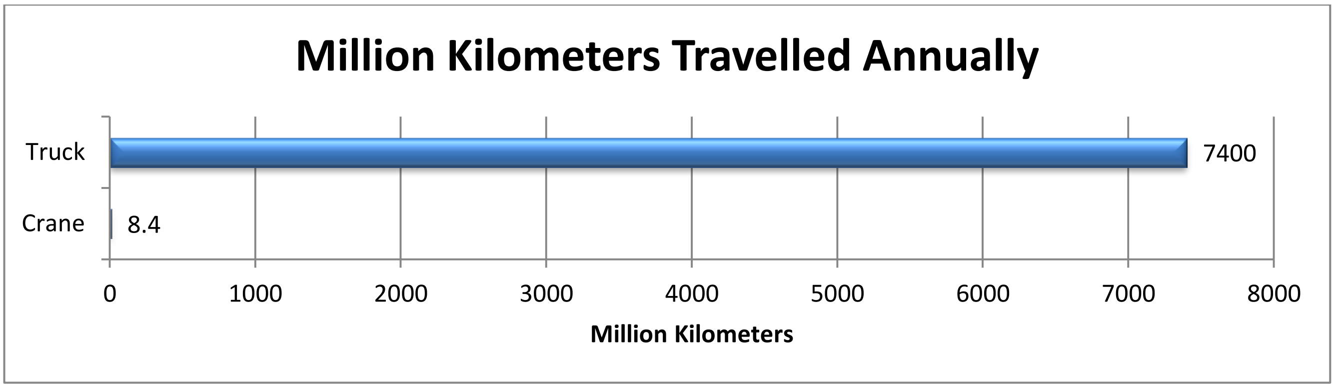

Figure 9: Cumulative Distance Travelled

The Australian Bureau of Statistics also provides a measure of tonne-kilometers travelled for freight carrying vehicles. In 2012, articulated trucks cummulatively travelled 151 Trillion tonne-kilometers.[5] Comparatively, All Terrain cranes travelled 512 Million tonne-kilometers. For every one tonne that an All Terrain crane loaded the road one kilometer articulated trucks loaded the road one tonne 295 kilometers.

<u>Conclusion</u>
Based on the three studies sited in this report there is substantial, independent evidence that supports the improved dynamic response on bridges from the use of hydro-pneumatic suspensions. These suspensions have been utilized on 100% of All-Terrain cranes since All-Terrain cranes have been in production in the mid-80s.

<u>Proposal</u>

Table 2: Proposed Bridge Design Load Factors

Vehicle Type	Dynamic Factor	Load Factor	Suspension Type
Standard Semi Trailers	1.4	2.0	Mechanical or Air Spring
Heavy Platform Low-Bed Trailers w/ Speed Restrictions	1.1	1.5	Hydro-pneumatic
Cranes – traditional suspension	1.3	1.8	Mechanical
Cranes – modern suspension	1.1	1.5	Hydro-pneumatic

Truck chassis cranes are designed to comply with existing axle limits from the manufacturer. While it should be noted that the load factor of these cranes should be the same as All Terrain Cranes with Hydro-pneumatic suspensions the proposal to increase their axle capacity limit is not being considered. The extent of this document and the support documents are to assist the industry with the adoption of axle limits that allow the crane to operate on road as designed by the manufacturer. Reducing the Dynamic Factor for cranes with hydro-pneumatic suspension to 1.1 represents the data measured in Study #2 and Study #3. Reducing the Load Factor to 1.5 is rationalized by adopting the same Load Factor as Heavy Platform Low-Bed Trailers as cranes are registered in approved transport configurations without divisible loads.

Brandon Hitch
CICA Engineer

References

1) CIAQ President’s Report, 20/8/2010
2) University of California at Davis / California Department of Transportation
3) The Stress on a Bridge by Heavy Vehicles with Different Axle Suspension / University of Stuttgart and Engineering Bureau Leonhardt, Andra and Partner.
4) Effects of Hydro-Pneumatic Suspension on Short-Span Bridge
5) 9208.0 – Survey of Motor Vehicle Use, Australia; Australian Bureau of Statistics