RAIL-WHEEL RESONANCE
EFFECT OF HIGH AXLE LOADS

by

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What is Resonance?

“Why are soldiers specifically asked to never march in unison on a long span girder bridge but are instructed to walk at random?” This is a very popular question in High School Physics.

The reason is that all materials vibrate when stressed within elastic limits. If the body is excited by a complementary reciprocating load at the same frequency, the two amplitudes will keep adding up. It will cause reinforcement of amplitude which will quickly reach unsafe limits. A long span girder bridge will have a natural frequency of one or two seconds and troops marching in rhythm and in unison could synchronize with these natural vibrations. Random walking will break the pitch and prevent such an occurrence.

Effects of resonance

Perhaps the most famous case of resonance is of The Tacoma Narrows bridge in the USA. This free suspension of 2600ft span opened 1st July 1940 but, on 7th November 1940, was torn to bits in a rather moderate wind which caused the deck to heave & twist like a dhoti being shaken dry. The crescendo took several hours to reach and the complete destruction of the bridge has been recorded on film. At that time, wind tunnel technology was still in infancy and the span was designed with very supple stiffeners which resonated with the wind-induced vibrations. Subsequent investigations revealed that if an adequate number of openings had been left in the floor decking, identity of the two frequencies could have been avoided and the storm would have harmlessly passed by.

Rail-wheel resonance

The same situation will arise with Railway trains if the periodicity of oscillation of the wheels or springs and the occurrence of track discontinuities were to concur. However, this does not happen. Designers take this factor into account and such resonance is not allowed to take place under normal circumstances.

For example, on Broad Gauge, our vehicles have wheels of 1000mm diameter (40” in the olden days) and a conicity of 0.05. Consequently, the wave length of the sinusoidal lateral motion of the wheel is around 18m or 60ft. There is therefore no risk of this wave resonating with the Rail joints which are 13m apart. In fact, in 1850, when Col Molesworth recommended the 5ft 6in gauge to Lord William Bentick, the Governor General for adoption in India, it was noted that this would clash with the Standard Rail lengths of 30ft and 60ft then in use in England. Hence, 39ft and 42ft Rails were adopted in India to avoid resonance between the wheel motion and the occurrence of Rail joints.

Frequency and wave length

Since the lateral oscillation of the wheel set follows a fixed wave length, the frequency varies with speed. In the above case, the periodicity would be 1Hz or one cycle per second if the train is running at 66kmph. It is 2.3Hz at 140kmph.

On the other hand, the vertical oscillations of the vehicle are generated by the springs and have therefore a fixed time period of oscillation and not a fixed wave length of so many meters. The wave length varies with speed while the number of cycles per second is fixed for the particular static spring deflection.

Till around 1950, all vehicles on the Indian Railways by and large, had leaf springs and Resonance was less insidious. Leaf springs are self dampening and the build up of resonance is slow. Today, with coil and helical springs, the build-up is rapid and can be catastrophic.

Propensity of brand new NCL wagons to derailment on straight track

My own first experience of resonance was in 1979. On SERly, Nagpur Division Narrow Gauge, we had been having frequent derailments of the newly introduced NCL Wagons on fairly good track without the slightest clue except that they derailed only on straights, never on curves. After discounting all other possibilities, our Committee decided to travel inside a wagon to measure all the three periods of oscillation. No measurement was really found necessary. We were literally tossed around and almost thrown out of the vehicle at a particular speed of 27kmph. There were no such violent oscillations either at lower or higher speeds. We then equated the periods and arrived at our conclusion that the vertical oscillations of the coil springs coincided with the frequency of Rail joints at that speed. However for confirmation, we checked up all the 30 odd derailments and found that every one of them had taken place on track with 30ft long Rails, never 39ft or 42ft long Rails. All these standard lengths were existing in track in equal measure.

Those days, it was usual to crop old 75lb (per yard) BG Rails and use them on Narrow gauge. With 30ft Rails, the time taken to traverse 30ft was exactly equal to the periodicity of the coil springs. That is why the older model wagons which had leaf springs did not derail; nor did the NCL wagons derail on longer Rails. Nor also on curved track where the joints were staggered and the resonance did not break pitch. The wagons were thereafter all retrofitted with stiffer springs and the phenomenon ceased.

It is to be noted here that if this had happened with Passenger coaches, the problem would have been noticed on the very first day. There would surely have been passenger complaints about the violence of vibrations. With Freight wagons however, there were no people to report and it took about three years for the diagnosis to link derailments with the vibrations caused by Resonance.

Severe vibrations in High speed Locomotives on the Saudi Railways, 1995

In the middle of 1994, RITES were asked to investigate a newly developed phenomenon of very violent oscillations of their High Speed GM Locomotives as soon as they passed 110kmph even though they had been running at 150kmph without any problems for some years before.

After extensive investigations, we found that the cause was the change over from a uniform 1 in 20 tread conicity to a “Worn wheel profile” obtained from Germany. This profile generated Longitudinal oscillations of the same wave length as the Rail length and this resulted in violent resonance at a speed of 110 kmph when the vertical oscillations too reached the same wave length.

In confirmation, it was seen that these vibrations stopped abruptly as soon as the Locomotive entered a curve and reappeared about one kilometer after exit from the curve. Also, there were no vibrations on the coaches which had softer springs or Freight cars which had stiffer springs.

The solution was simply to revert to the AAR Standard 1 in 20 wheel profile. These locomotives are still running now in 2010 without any vibration problem.

This raises the question of why there was no serious problem of such vibrations from the very first day of introduction of the new wheel profile. The answer lay in the Rail joints. If the joints had been fishplated, there would surely have been a severe Resonance from the very first day of the introduction of the UIC profile. SRO’s line No 1, however, has excellently aligned welded joints in its “All CWR” route and there was, initially, no scope for Resonance.

But, in this area, one has the phenomenon of the welded joints slowly getting harder than the rest of the Rail. The hardness of the UIC 860-O Grade 900A Rails having a tensile strength of 90Kg/sqmm is normally in the region of 270BHN. This was generally the value obtained by the study team while measuring the hardness of the non-wearing parts of the Rails. This was confirmed by the Laboratory test in India. However, the measured hardness over the Railhead was in the region of 350 to 380BHN. Going further, the hardness of the welded areas was found to be still higher and in the region of 400 to 450BHN.

Apparently, the sand embedment had work-hardened the rolling surface to a greater extent at the welds than elsewhere.

Hence, the rail surface tended to become harder with traffic and the sand embedment. This is called the “work hardening process”. The welds become harder than the original Rail after work hardening due to Pearlitic content.

Thus, as the Rails wore out under traffic, the welded portion suffered a little less wear than the rest of the Rail and this created a miniscule dominance, which though not harmful in itself, could create resonance when repeated over hundreds of joints. Hence the one Kilometer lag.

In 1995, Resonance was able to build up only after passing 60 to 100 joints. As the magnitude of the defect increased with wear and tear, the propagation would have surely become faster and faster. As years pass, the violence of the vibrations was likely to become stronger still. However, this became only a theoretical issue since the SRO switched over to the AAR profile immediately after our diagnosis and Resonance was killed.

Lessons learned

Resonance is a very rare occurrence and most of us may never run into it during our service of a life time. We never think of it as a possible cause for any track problems and overlook it even when that happens. For this purpose, it is necessary for all Railway Track Engineers, especially those in IRICEN & RDSO, to know how it happens, how it is to be calculated and measured and how to overcome or ameliorate its dangerous effects.

Now with the introduction of new wagons of high axle load on the DFC and also extra springs on the existing wagons, track men should be conversant with the resonant frequencies. Every time the wheel conicity is changed, or the deflection is increased, the wave lengths have to be calculated afresh before safety certificates are issued. Above all, the new high speed coaches have very soft springs and their spring characteristics should be known to and understood by all Civil Engineers.

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