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Effect of Rail Welding Defects on the Railway Steel Bridges Response

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Abstract. This Paper aims to investigate the effect of defected weld and joints that have a cap or dip in their geometry on the structural behaviour of steel bridges. The study is established by using the finite element numerical model applied by ABAQUS Program to simulate a train track bridge interaction model. Nonlinear dynamic analysis is used in this study which applied on the case of non-ballasted track with timber sleepers that's the track components are fixed directly to the bridge elements (stringer and cross girder). The results of this simulation are compared with those calculated from international codes belong to Bridge acceleration.

Keywords: steel bridges; Train track bridge; Impact factor; Rail weld; Rail joint.

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1. Introduction

The track can be classified as welded or weldless in the adjoining rails connection. The traditional tracks are connects the ends of adjoining rails by using a two fishplates coupled by four to six bolts. These type of joints are weaken the track structurally due to the existence of rail gap, height difference. Consequently, a railway track structure without rail joint can be the preferred method of joining rails in track, this mean that the continuous welded rail (CWR) can shows a greater advantage over bolted rail in improving dynamic behaviour of train–track interaction system. The most common rail welding processes are flash-butt welding, thermite welding, and gas pressure welding and enclosed arc welding.

Rail joint or weld geometry have a vital role in the impact loads on the track. Although the continuous weld rail is successfully techniques for improvement of the rail running surface compared with bolted rail joint, however the rail welds still represent a discontinuity on the rail

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top surface due to variation in the material characteristics such as hardness, strength, weld defects, and rail surface irregularities, which All of these factors are combined to produce higher or localized dynamic loads on the track structure. The imperfect geometry at non-ground welded joint may, in some cases, lead to high dynamic contact forces, contact stresses and sub-surface shear stresses Ilaria [1]. The dynamic amplification of the impact forces due to weld defect can be substantially increased with the increments of train speeds as Explained by Esveld, and Zhai and Cai that stated and Cited by Alex [2]. Otherwise the defect called as squats are found only occasionally at locations of obvious stiffness changes, the track-short defects such as loose fishplate bolts and the contact between fishplates and the rail head is causing large contact force variation ZILI LIA[3]. The dynamic interaction between wheels and rail joints causes localized damage and failure of track, in addition the relationship between the maximum contact force and the running speed over defected weld that have a dip in their geometry is not linear (not even monotonically increasing) Nekane Correa [4]. The presence of a vertical dip at Insulation rail joint due to the deteriorated foundation or deformed rail head had more influence on the dynamic loads than increasing the joint gap from 6 mm to 11 mm (In: Suzuki and Akhtar which stated and cited by Hossein [5].

This paper aims to study the effect of defected weld and jointed rails that have a cap or dip on their geometry respectively on the structural behaviour of steel bridges, which it is an important to predict excessive impact loading due to these defects. These defects may induce increasing in stresses and strains on the bridge elements, and actually can affect directly on the comfortable of passengers. according UIC Leaflets 776 - 1R [6], Eurocode EN 1991-2 [7]; the track irregularities can be involved in the railway bridge design by using the dynamic factor, which some of empirical equations had been given to take the effect of track irregularities belong to dynamic amplification factor. Consequently and in accordance with UIC leaflets the Track irregularities included in the dynamic amplification factor has been fixed by assuming a vertical dip in the track of 2mm over length 1.0m or 6mm over length 3.0m, and an unsprung mass of 2t per axle.

2. Simulation model and numerical analysis:

2.1 Simulation of the Proposed Bridge

The proposed simulated bridge is one of railway steel bridges existing in Egypt, the bridge has total length 320m divided into five bays two continuous spans and simply supported span on the mid (swing type). This work focuses on the continuous span 62.4 m, 64.8m long span closest to

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the end of bridge (127.2m total length). Figure 1(a) shows a perspective of the bridge and Figure 1(b) its side views wide 9.3m.

A Three-dimensional numerical model is developed using the finite element package ABAQUS (2017) to simulate the proposed track-bridge model as shown in Figure 2, The Bridge is restrained by a hinged supports at the middle of the continuous spans, and roller supports is assigned at the ends.

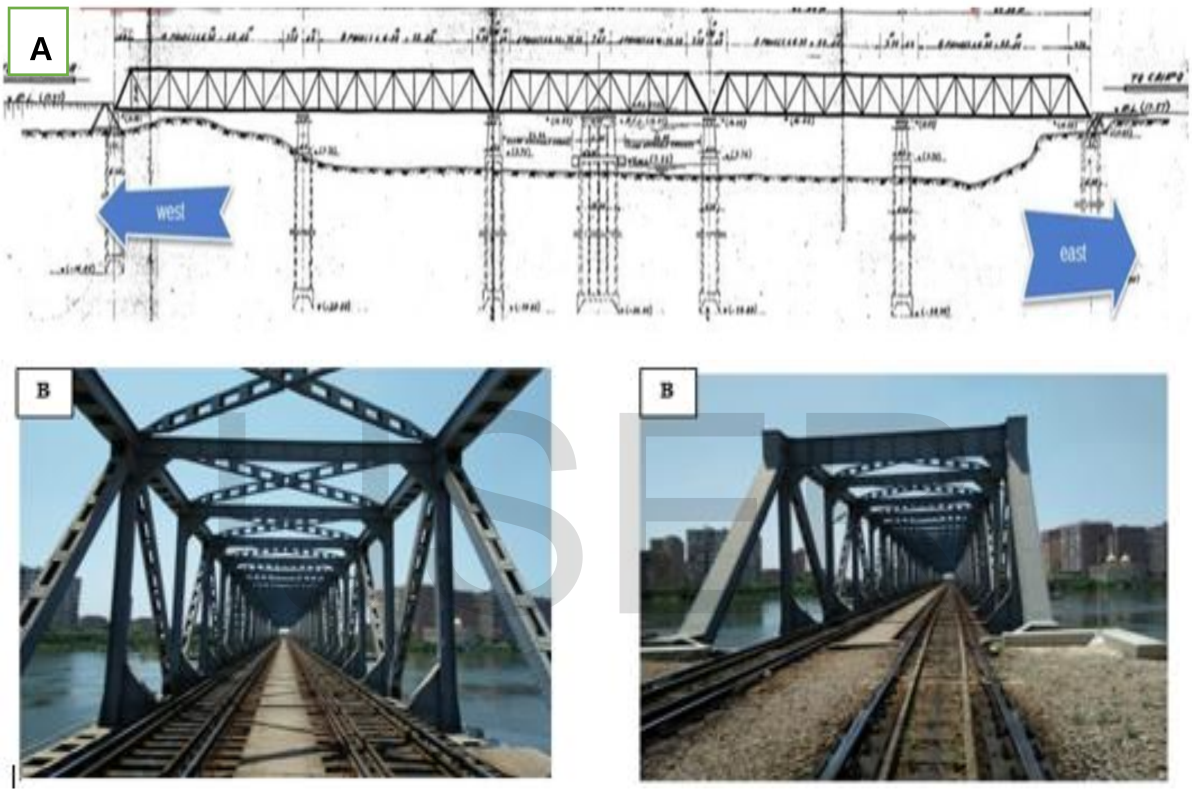

Figure 1 Proposed Bridge Existing in Egypt (a) perspective view; (b) Side Views.

2.2 Track Model

In this study, the non-ballasted track type is used and formulated by rails and wooden sleepers supported directly to bridge elements as shown in Figure 2. The rail is simulated as a solid extrusion shape type on discrete wooden sleepers. The two extreme ends of the rail are separated by an expansion joint, which the rails are extended by suitable lengths before the beginning of the bridge related to the proposed train length used in simulation. The sleepers are modelled as rigid rectangular beams fixed directly to the bridge stringers and cross girders. ABAQUS wire feature is used to represent the relation between (rail and sleeper) or (sleeper and stringers) as pin or beam connector section (as the concept of rigid link). In this study. The interaction between rail and sleepers or sleepers to stringers is taken into account by the concept of rigid link refer to Myung-

Kwan Song (2003).

In this study are defects are simulated of rail weld defect and joint as shown in Table 1.

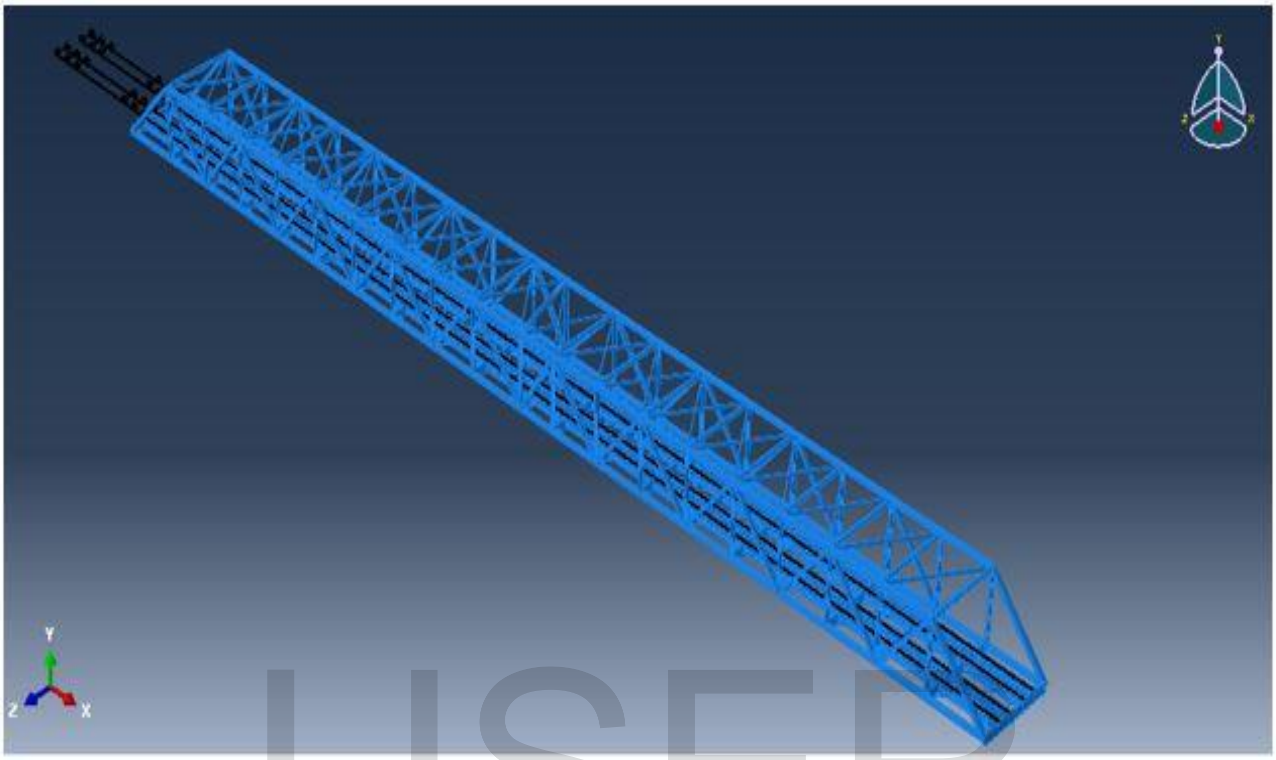

Figure 2. Captured Photo of the Bridge Model built in ABAQUS

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2.3 Train Model

The train is simulated as shown in Figure 2, and a two axle only is simulated to investigate the influence of weld and joint defects on the bride elements as the scope of this study. The part of train used in this study (German Locomotive: Henschel, 128ton /6 wheel sets). Henschel Locomotive has two identical bogies with three wheelsets each, the length of Locomotive is about 22 m as shown in Figure 3.

2.4 Numerical Analysis Models

The ABAQUS models are built to investigate the influence of weld and joint defects (listed in Table 1) on the bridge structural behaviour as the scope of this study.

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Table 1- Describe Different Cases of Wheel and Rail Defects has been Simulated in This Study

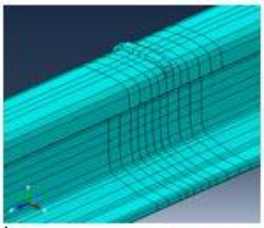
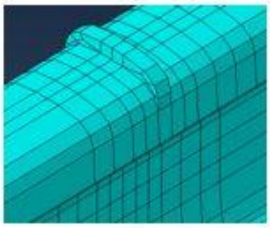
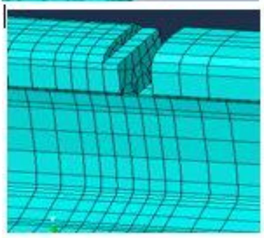
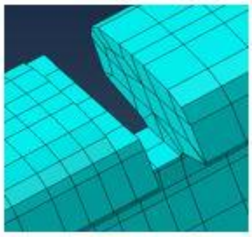
Type	Size (mm)	Shape or Schematic	Simulated Shape	
Weld Defect* (Length, Cap)	10x7.5 10x10			
Joint Defect * (Gap, Notching)	10 20			
Smooth Track	Track Without Defects with Train Running Speed at 120 km/h *All Rail defects are Proposed to be located at the middle span of the bridge			


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Figure 3. Locomotives (German: Henschel) loading data according ENR Specs.
(128ton / 6 Axle – Axle spacing 1.85m, mid spacing 9.0m)

3. Results and Discussion

On this section, various types of rail defects (listed in Table 1) are simulated and analysed in nonlinear dynamic model. The dynamic analysis responses is investigated when the train is pass through the bridge at speed 120km/h. the results of the evaluation indices are given in Table 2.

Table 2 Simulation results due to wheel and rail defects on the bridge response at fixed speed 120km/h (Load assign as moving load and moving mass)

Type	Size (mm)	v. acc. (m/s^2) Moving load	v. acc. (m/s^2) Moving mass	v. disp. (cm)	DAF_U	stringer strain (με)	DAFε stringer	x.girder strain (με)	DAFε x.girder
Smooth Track	no defect	3.00	2.60	1.10	---	161	---	170	---
Joint Defect	Gap 10	2.36	2.05	1.10	1	180	1.12	178	1.05
Joint Defect	Gap 20 With notch	Nonlinear dynamic analysis 3.80	3.29	1.10	1	178	1.11	172	1.01
Weld Defect	Cap 7.5	3.70	3.21	1.00	0.91	188	1.17	199	1.17
Weld Defect	Cap 10	3.35	2.91	1.00	0.91	187	1.17	199	1.17

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3.1 Influence of Rail Welded and Bolted Joint Defects On the Bridge Response

The imperfect geometry at non-ground welded joint may be in some case, lead to high dynamic contact forces, contact stresses and sub-surface shear stresses. In addition, the high impact loads caused by the rail weld surface irregularities result in high stresses and localized plastic deformations not only at the rail weld but also at base metal near the rail weld. The dynamic amplification of the impact forces from bad welds can increased with the train speed Ilaria [1], ZEFENG [9], and Alex [2].

The contact force between the wheel and rails, stresses and strains are more sensitive to the height difference value than to the train speed and axle load. Larger contact force easily leads to larger stresses and strains, and so results in severer damage and failure to rail joint. On other hand, the presence of a vertical dip at intermediate rail joint due to the deteriorated foundation or deformed rail head had more influence on the dynamic loads than increasing the joint gap from 6 mm to 11 mm W. Cai [10], Hossein [5].

In this study, set of models has established to simulate non-ground welded joint on various pulse caps (7.5, and 10mm). In addition, another simulation for the negative pulse bolted joint with various Gaps (10, and 20 with notching). The results show that non-ground defected weld joint has more influence on bridge acceleration than the intermediate rail bolted joint. Although that the continuous weld rail tracks is preferable to use in high speed lines than bolted joints, as advised in the numerous references and international codes, so that the track with CWR need to be more caring to maintenance level. It also can be seen the weld defect with cap 10mm has slight effect on the vertical acceleration more than with caps 7.5. while mean increasing in joint gap that can be occurred due to summer and winter effect on the track can be caused increasing on the bridge acceleration W. Cai [10], Hossein [5]. In addition, weld and joint defects have small effect on the bridge Displacement.

On the other hand, the weld defect can affect drastically on the strain of bridge elements as stringer and cross girder. The strain of stringer and cross girder are affected drastically which DAFε is increased to 17% due to various defect cap sizes.

Meanwhile, and regarding joint defect, the strain of stringer can be affected drastically which DAFε is increased from 11 to 12% due to different gap width. On contrary, the cross girder strain is increased within 5%. This is because the track is fixed directly to the stringer.

Hence, there is slight difference between strain results in weld and joint defects but has big effect comparing with smooth track. The vertical acceleration and displacement at mid span for caped weld defects and joint gas defects are plotted in time domain as shown in Figures (4 - 5 – 6- 7).

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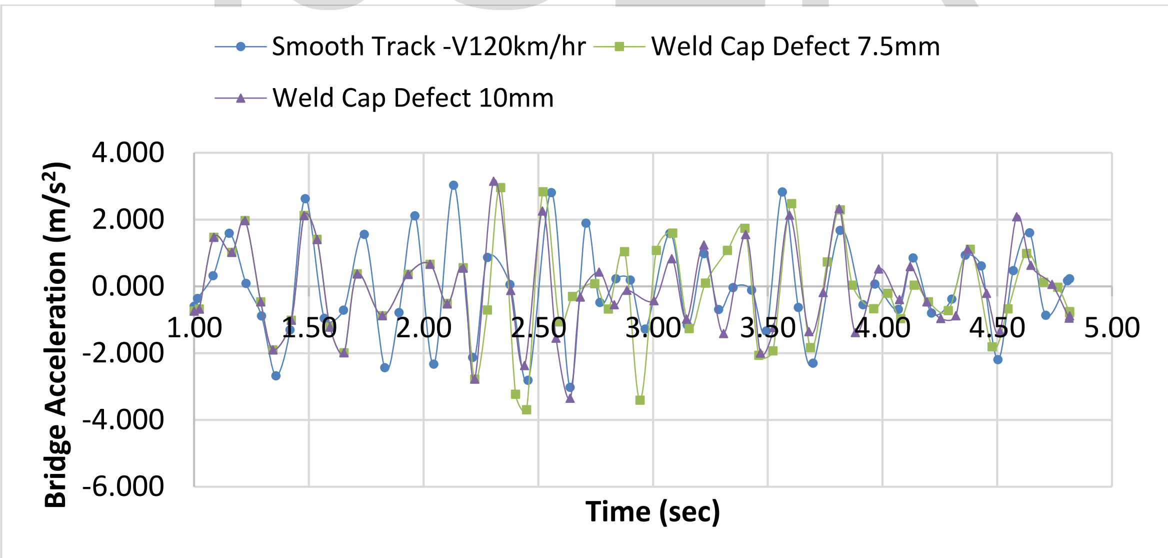

Figure 4. Vertical acceleration in time domain at bridge mid span due to weld defects at speed 120km/h, when moving loads are applied (can be reduced by 13.33% to get values when moving sprung mass).* From 0-1sec is the stabilizing step with a whole gravity load.

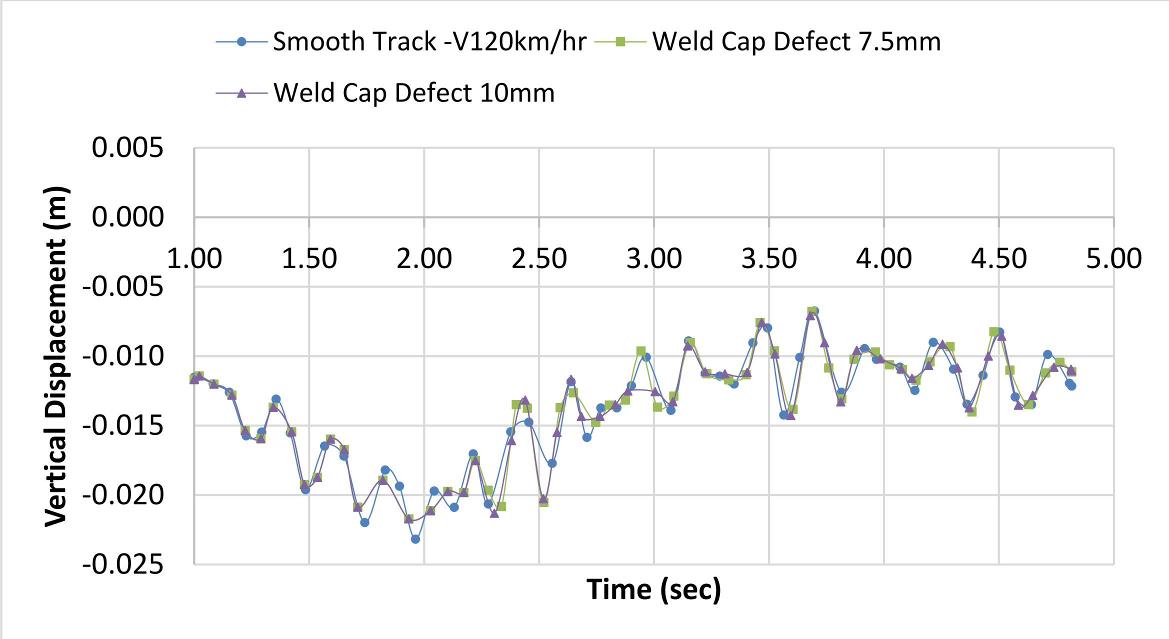

Figure 5. Vertical displacement in time domain at bridge mid span due to weld defects at speed 120km/h, when moving loads are applied. * From 0-1sec is the stabilizing step with a whole gravity load.

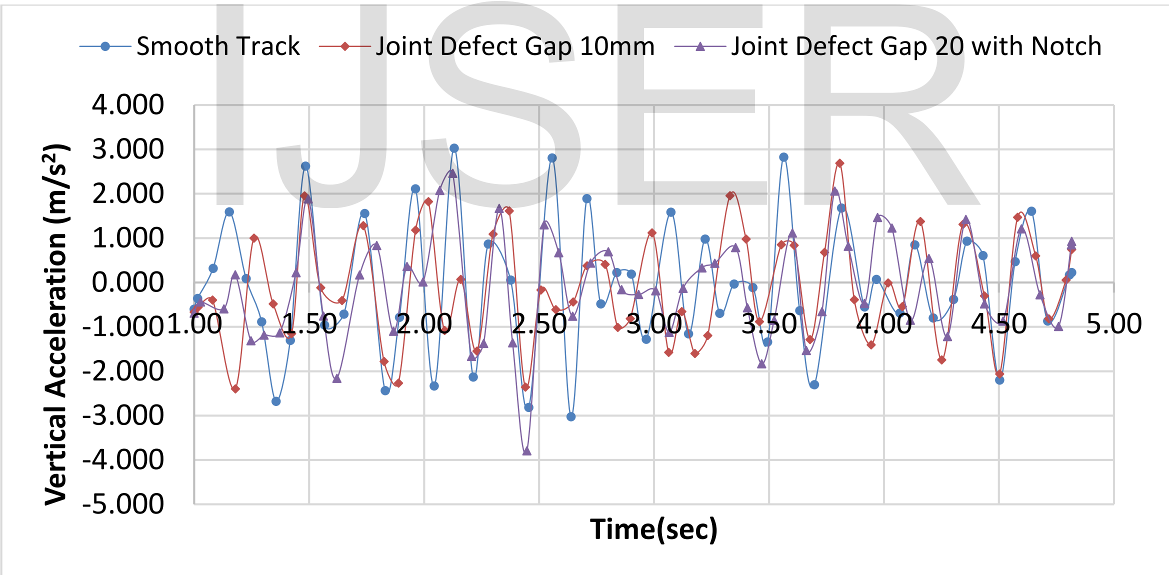

Figure 6. Vertical acceleration in time domain at bridge mid span due to joint defects at speed120km/h, when moving loads are applied (can be reduced by 13.33% to get values when moving sprung mass). * From 0-1sec is the stabilizing step with gravity load

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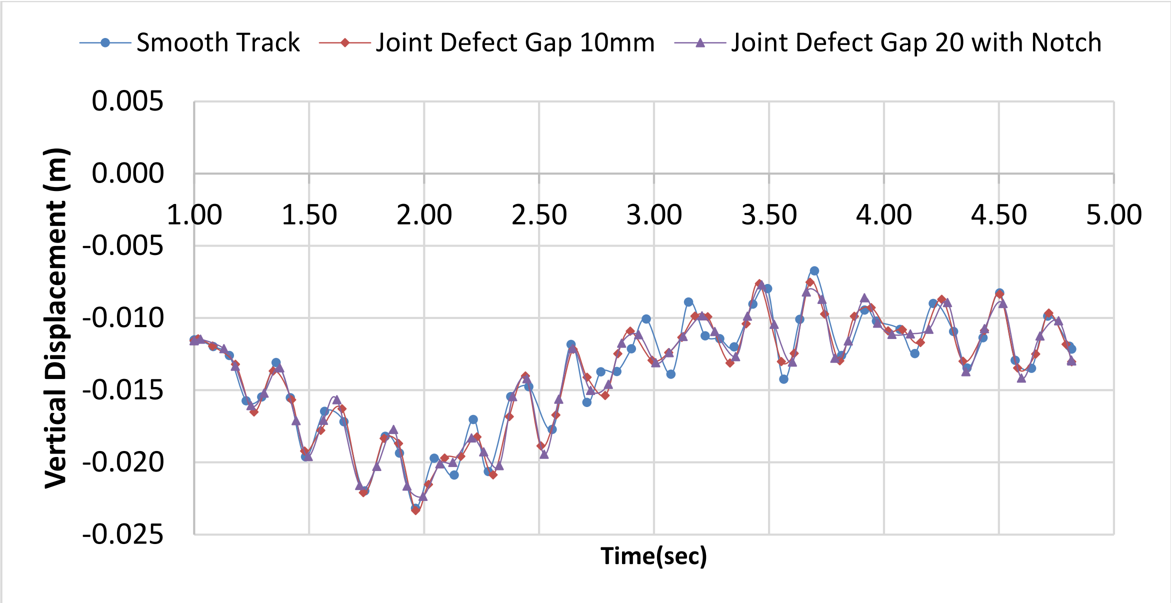

Figure 7. Vertical displacement in time domain at bridge mid span due to joint defects at speed 120km/h, when moving loads are applied. * From 0-1sec is the stabilizing step with gravity load.

4. Conclusions

Based on the simulation results, it can concluded that:

- The simulated track defects considering in this study are such as non-ground welded joint on various Pulse Caps (2.5, 7.5, and 10mm). Negative pulse bolted joint with various Gaps (10, 20mm, and 20+10mm notching), and rail breakage 30x30mm.
- Track irregularities considering by UIC and Eurocode included in the Dynamic amplification factor has been fixed by assuming a vertical dip (i.e. Wear Defects) in the track as 2mm over length 1.0m or 6mm over length 3.0m with moving of unsprung mass of 2 ton per axle.
- The bridge response (displacement) has a small influence affected by track defects.
- Railway Bridge acceleration has highly influence due to proposed track defects in this study, which can increased by twice times from the passenger comfortable limit (a max ≤ 2 m/s2) otherwise that can exceed the maximum limits advised by codes (a max ≤ 5 m/s2).
- The strain of railway bridge elements as stringers and cross girders is affected drastically due to existing of track defects, which can be increased by 17% due to the proposed simulated defect in this study. This is very large effect compared with that calculated by Eurocodes.

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