Dynamic response of underground structures at railway transition zones

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ABSTRACT

Transition zones are places where the railway embankment is interrupted by structures such as bridges, culverts, and tunnels. Maintenance of transition zones is one of the main concerns for railway infrastructure management due to the need for more frequent additional maintenance. The characteristics of the backfill and the stiffness of culverts have a significant impact on the performance of railway tracks. This study investigates the effect of culvert slab stiffness on soil dynamic response under a twin-block sleeper, concrete sleeper, and timber sleeper. A validated finite element model (FEM) using experimental data was adopted as a main research tool. The stiffness of the culvert slab is represented by the thickness/breadth (T/B) ratio. Peak values of vertical displacement, shear stress, and vertical acceleration were adopted as the key dynamic response indicators. The use of twin-block sleepers proved to be an optimum solution that generated the least dynamic response throughout the soil section for all culvert cases with different values of slab stiffness. At 0.25 T/B, a reduction of 41% in the peak shear stress was observed. A significant reduction was achieved in both peak vertical displacement and peak vertical acceleration using a slab stiffness of 0.375 T/B. The results can help improve railway track performance and durability.

Keywords: Railway, Transition zones, Dynamic Response, Stiffness, Sleeper types

INTRODUCTION

Railway track structures can be classified into two main groups: superstructure elements and substructure elements. Superstructure elements are composed of rails, fastening systems, rail pads, and sleepers, while substructure elements are a combination of ballast, sub-ballast (capping layer), and subgrade layers. **Fig. 1** illustrates a typical ballasted railway track. As the boundary between superstructure and substructure, railway sleepers have a crucial duty in retaining their structural integrity and decreasing the contact pressure to a level tolerable for the ballast layer.
Railways are essential to society and the economy. Nearly 9,435 kilometers of Egypt's conventional railway are utilized to convey both people and goods [2]. Currently, there is a wide interest in railway tracks construction and rehabilitation projects in Egypt with a total cost of about EGP 147 billion [3].

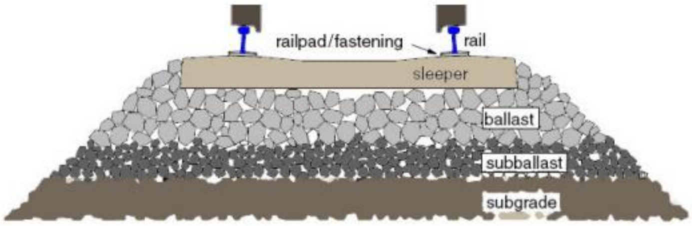


Fig. 1. Components of Railway [1]

Culverts are structures which allow water to flow under the railway. The type of sleepers used and the culvert size affect the performance of railways.

In railway tracks, transition zones are places where the embankment is interrupted, such as bridges, culverts, and tunnels. Railway infrastructure management is deeply concerned about these areas because frequent significant additional support is needed to maintain the line, level, and riding quality. Maintenance of transition zones occurs two to four times more frequently in the Netherlands than on the "free" track [4] & [5].

A comprehensive study focused on hazard risk identification and assessment of water control structures' construction and rehabilitation projects in Egypt. This investigation examined various risk variables that may arise during these projects. A cost contingency of 11.5% above the original budget and a time contingency of 16% beyond the total baseline schedule would be required to effectively address these identified risks [6].

The characteristics of the backfill have a significant impact on how well the transition zone performs [7]. Analyzing the linear dynamics of these transition zones, investigating potential mitigation methods, and getting to conclusions about significant indicators like force transmission and energy dissipation will help us understand how ballast settles in railway track transition zones with different levels of stiffness, these findings have potential to provide valuable insights for assessing the development of ballast settlement over time [8]. Both the effect of soil inertia and soil/structure relative stiffness have an impact on the seismic responses of underground structures; therefore, it is crucial to give these crucial factors more consideration during the seismic design of underground structures. [9].

(a) Culvert [10] (b) Bridge [11]

Fig. 2. Transition zones examples

Railway infrastructure incorporates a diverse range of sleepers from various brands. These sleepers are typically constructed using timber, concrete, and in some instances, steel. Each material has its properties and characteristics to suit specific requirements. Timber sleepers are designed to have a lifespan of approximately 20 years, while concrete sleepers are intended to last for about 50 years. On the other hand, steel sleepers offer longer durability, with an expected lifespan of 50 years as well. By utilizing these different materials, the railway industry ensures that the sleepers can cater to varying demands and provide long-lasting support to the tracks and trains [12].

Due to continuously growing payload weight, timber sleepers are becoming less suitable for high-speed trains [13]. Concrete sleepers can gauge holding properties and provide a better line than timber sleepers. However, concrete sleepers are heavy and expensive, as well as incapable of delivering service life beyond 50 years [14]. The twin-block sleeper is made up of two reinforced concrete sections connected by a steel tie rod to provide a proper track gauge and suitable spacing among the aggregates in the casting [15]. Twin-block reinforced concrete sleepers, despite their significance and advantages, have received minimal research attention regarding their dynamic performance. Compared to mono-block sleepers, twin-block sleepers are significantly more composite; the interaction between the materials steel and concrete is more prominent. [16]

The advantages of twin-block sleepers include smaller size, reduced weight, enhanced lateral resistance, suitability for various load conditions, higher flexibility, and more elastic behavior.

Drawbacks of twin-block sleepers include higher contact pressure between the sleeper and ballast layer, which requires a deeper ballast depth and a rise in construction and maintenance costs. Another drawback of twin-block sleepers is the potential for block declination towards the center and the potential loss of track gauge over time [16].

Changing the shape of sleepers, such as using twin-block sleepers, has been studied and shown to increase lateral resistance by about 30%. Another advantage of twin-block sleepers is their higher flexibility and more elastic behavior compared to mono-block sleepers [16].

Twin-block sleepers have shown a 65% increase in lateral resistance compared to mono-block sleepers by modifying the interaction between ballast and sleeper. Moreover, the inclusion of vertical stiffeners to the bottom of steel sleepers and increasing the interaction between the sleeper and its bottom ballast can further increase the lateral resistance of twin-block sleepers by up to 140% through enhancing the passive pressures mechanism at the sleeper's bottom [16].

Lastly, the steel rod used in the twin-block sleeper design is susceptible to corrosion and wear and tear over time. This vulnerability may lead to reduced structural integrity of the sleepers, requiring regular inspections and potential replacement to ensure safe and reliable railway operation [17], where prestress levels play a major role in maintaining the high durability of sleepers when subjected to low-to-moderate repeated impact loads [18].

(a) (b) (c)

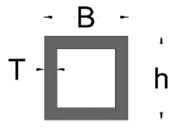
Fig. 3. Types of sleepers: (a) timber sleeper, (b) concrete sleeper, and (c) twin-block sleeper [19]

The existing knowledge on sleeper performance and culvert stiffness has provided valuable information about the behavior of sleepers and the impact of culvert stiffness on soil performance. However, there is still uncertainty about how the type of sleeper influences the soil behavior beneath railways. Therefore, the main objective of this research is to investigate the effect of timber, concrete, and twin-block types of sleepers on the dynamic response of soil at transition zones. A parametric study was conducted to identify the optimum thickness-to-width ratio of culvert slabs and walls concerning soil performance.

Methodology and validation

The current work was divided into two main phases (Figure 4). The first phase includes modeling and validation, where a 3D finite element model (FEM) was created by setting the geometry, assigning material properties, mesh generation, assigning dynamic loads of train, and static loads represented by self-weight, then assigning groundwater table level. Boundary conditions are then ascribed by defining ground and pile constraints. According to soil characteristics, using piles was required to achieve an acceptable response under high-speed train loads. Piles enhance uplift resistance under cases of high-water tables. The initial stress state of the soil is determined after calculation of the vertical stress under the weight of overlaying layers considering pore water pressure. Nonlinear time history analysis was performed to validate the model with the experimental data [20]. The second phase presented a detailed parametric study to assess the effect of sleeper type and culvert stiffness on the dynamic response of soil represented by the thickness-to-width ratio of slabs T/B (**Table 1**).

Table 1. Culvert dimensions (m)

	Culverts Dimensions	T/B ratio			
		0.115	0.150	0.214	0.375
	B (Breadth)	0.80	1.40	2.00	2.60
	T (Thickness)	0.30			
	h (Height)	2.00			

Midas GTS-NX was used as an efficient FE modeling and analysis tool, with high computational effort required to achieve current results concerning dynamic analysis and dense soil meshing. The time step was 0.001 seconds,. The mesh element types and size are shown in Table 2, where the dimensions of the 3D elements for different materials after model meshing varied from 0.05 m to 0.40 m, The mesh size was determined depending on mesh sensitivity analysis which is illustrated in Table 3 and Table 4 for soil and rail elements respectively. According to the soil profile and characteristics of every layer, the entire system of the soil and overlying structure was modelled as shown in **Figure 5**.

Table 2. Meshing element types and size

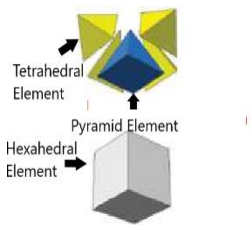
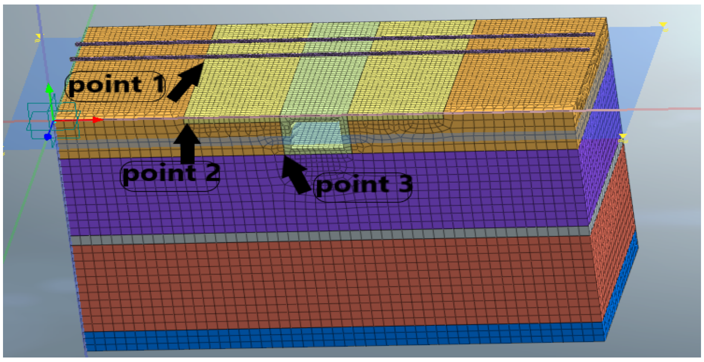
Material	Mesh Size (m)	Element Type
Rail	0.05	
Sleeper	0.1	
Ballast	0.2	
Culvert and Slabs	0.2	
Soil	0.4	

Table 3. Mesh sensitivity analysis in the middle of the first clay layer

Mesh size (m)	0.8	0.6	0.4	0.2
shear stress (MPa)	52.21	44.64	38.71	38.73
Vertical Displacement (mm)	7.21	6.43	5.21	5.22

Table 4. Mesh sensitivity analysis of rail

Mesh size	0.1	0.05	0.025
Normal Stress (MPa)	15.53	13.51	13.52



Point 1	under ballast/rail connection
Point 2	At the supporting slab edge
Point 3	At culvert base

Fig. 5: The FEM model of the culvert showing the selected three main points where the dynamic response was calculated

The FE model consisted of a concrete box culvert with external cross-section dimensions of 2.00 m by 2.00 m and a rectangular slab 0.30 m thick on both sides supported by piles with 0.30 m diameter and 10.00 m length. A longitudinal section of the culvert and soil profile is illustrated in **Figure 6**. The soil profile consisted of 2.00 m of a certain type of sand (namely, Sand 1) resting on 4.00 m of soft clay; a 30 cm thick layer of ballast was set to overlie Sand 1. Beneath the soft clay is a thin layer of another type of sand (namely, Sand 2) with a thickness of 0.50 m; then the soft clay extends downwards to a level of (-12.00) m under the groundwater table. The soft clay rests on a bed of sand named Sand 3 (Fig. 6).

The dimensions of the model are 20.00 m in length and 9.00 m in breadth. The rail is modeled as a 3D rectangular beam element with a rail width of 0.10 m, with a height of 0.14 m, and a density equal to 157.69 Kpa to match the rail moment of inertia and mass of the sleeper modeled using a rectangular
beam element. Timber and concrete sleepers' dimensions are 2.50x 0.20x0.15 m, while the twin-block dimensions are 0.7 m in length, 0.3 m in width, 0.25 m in height for concrete block, and 0.1 x 0.1 x 0.01
m for the Steel Angle. The distance between sleepers is 0.60 m. Loads of moving trains were modeled with the Sprinter T1 consisting of 10 train cars with 20 dynamic point loads with 124 KN.

The train velocity controls the created load which is applied to the analysis model to create a time load function for time history analysis using the dynamic nodal technique. The static loads are defined by applying a time-forcing function. In addition, the reference function is applied to define a linear/non-linear distributed dynamic load. Generally, it is used to define vibration, driving, blast, and railway movement loads.

The behavior of pile elements is the interaction between the parent element (soil) and pile elements like beams or trusses. This interaction can be obtained by the superposition of two normal responses and one tangent response. The shear/vertical stiffness is defined to simulate this interaction, assuming that the two normal directions undergo identical rigid body motion as the parent element, while the tangent direction undergoes nonlinear elastic motion.

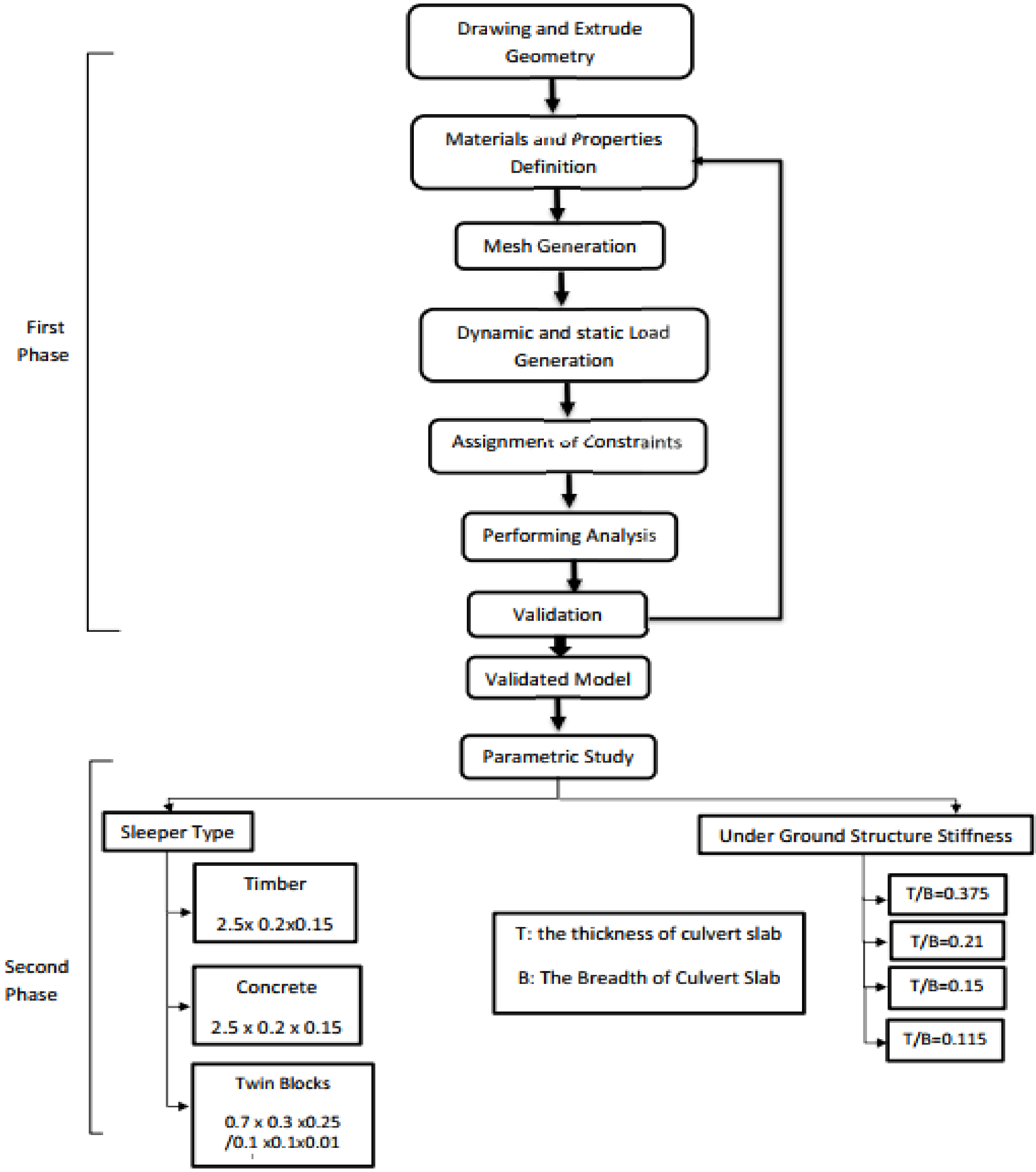


Fig. 4. Analysis flow Chart

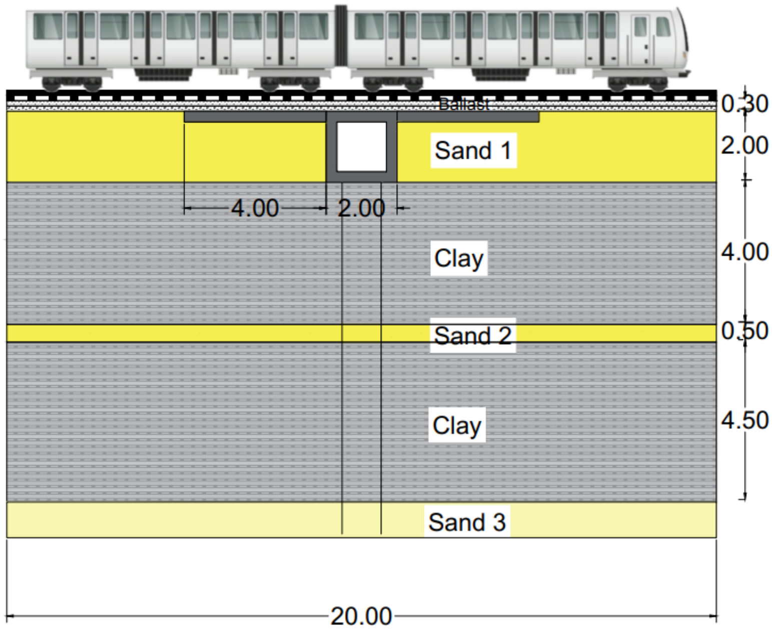


Fig. 6 Cross-section of the FE model for the soil-structure system

Table 5 Material Properties

Material		Modulus of elasticity, *E* (MPa)	Poisson's ratio	Permeability (m/s)	Dry Unit weight (KN/m^3)	Moist unit weight (KN/m^3)	void ratio	Damping ratio (%)
Sand 1		100	0.30	0.001	17.00	19.00	0.67	0.50
Sand 2		113	0.30	0.001	17.00	19.00	0.67	0.50
Sand 3		143	0.30	0.001	17.00	19.00	0.43	0.75
Clay		8.3	0.50	0.001	17.00	17.00	2.33	1.00
Ballast		200	0.20	-	18.00	-	-	-
Timber Sleeper		10 x 10^3	0.10	-	5.10	-	-	-
Piles		18 x 10^3			24	24	-	5.00
Concrete Sleeper		21 x 10^3	0.30	-	25.00	25.00	-	5.00
Twin-Block	RC Block	21 x 10^3	0.30	-	25.00	25.00	-	5.00
	Steel Angle	210 x 10^3	0.20	-	80.00	80.00	-	3.00

The relationship between the soil and the pile tip element is represented by the behavior of the pile tip element. The tangent direction behavior encounters nonlinear elastic motion, whereas the normal direction behavior along the element coordinate axis at the pile tip is considered to experience equal rigid body motion as the parent element. The nonlinear material model or a value for fully plastic behavior is applied to numerous curves as allocated to the pile element. Through default stiffness, bearing power, or ultimate strength, the pile and pile tip parts both show nonlinear behavior. Functions are used to specify nonlinear behavior, and a 3D table is supported for piles to define several functions at various depths. It is believed that the slope and yield strength experience fully elastoplastic behavior depending on height when defining the shear stiffness of the pile using yield strength. (**Figure 7**).

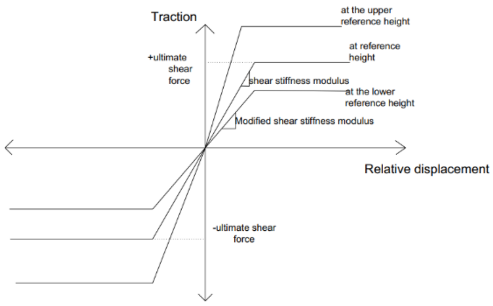


Fig. 7 Relative displacement-frictional force relationship [21]

An interaction formula that determines the tangent/normal stiffness is used to estimate the shear/normal stiffness of the pile element because the impact of the surrounding ground material is larger than that of the pile stiffness or sectional characteristics using **Eq. (1)** and **Eq. (2).**

$$K_n = \frac{E_{oed,i}}{Lxtv} \quad (1)$$

$$K_t = \frac{G_i}{Lxtv} \quad (2)$$

where $$E_{oed,i} = \frac{2xG_i x(1-v_i)}{(1-2xv_i)} \quad (3)$$

(where ν_i = interface Poisson's ratio, the interface is used to simulate the non-compressive frictional behavior and takes on a value of 0.45 to prevent numerical errors.)
t_v = virtual thickness (value between 0.01-0.10, where The value decreases as the stiffness differential between the ground and the structure increases).
Calculate the Dynamic Coefficient of Soil Illustrated in **Eq. (4)** and **Eq. (5)**

$$G_i = Rx\, G_{soil} \quad (4)$$

$$G_{soil} = \frac{E}{2x(1+v_{soil})} \quad (5)$$

R = Factor of Strength Reduction
The following list shows the general Strength reduction factor for structural members and nearby ground conditions.
Sand/Concrete = R : 1.00~0.80
Clay/Concrete = R : 1.00~0.70
GTS NX supports nonlinear time history analysis that includes geometric and material nonlinearity, and it is based on implicit time integration. Equilibrium equation in nonlinear time history analysis uses the HHT-α Method [22] as implicit time integration like for linear time history analysis and uses the following modified equilibrium equation **Eq. (6)**.

$$\frac{\partial}{\partial t}(Mv^{n+1}) + (1+\alpha_H)[Cv^{n+1} + f^{int,n+1} - f^{ext,n+1}] - \alpha_H[Cv^n + f^{int,n} - f^{ext,n}] = 0 \quad (6)$$

Where:
M : Mass matrix
v : Velocity vectors
: Mass proportional damping coefficient
C : Damping matrix
Nonlinear time history analysis was performed on the convergence solution for each time step using the nonlinear finite element solution; a method of converging the accumulated incremental solution from iterative calculations to the correct solution. In **Figure 8**, ${}^{t}f_{ext}$ and ${}^{t+\Delta t}f_{ext}$ each represent the external forces at time t and time t+Δt and the solution and incremental solution between time and time can be expressed as the following relationship Eq. (7):

$$u^{t+\Delta t} = u^t + \Delta u \quad (7)$$

Δu: incremental solution occurring at time increment t.

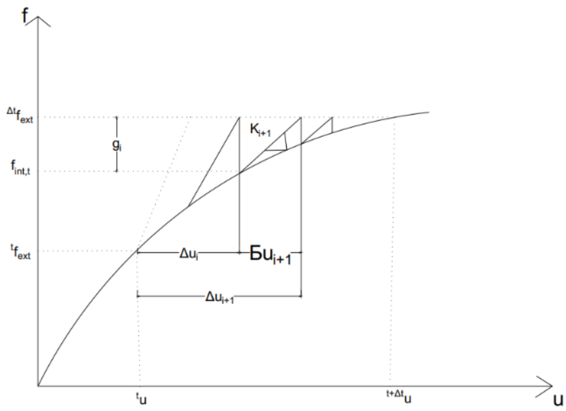


Fig. 8 Accumulated incremental solution and nonlinear finite element convergence [21]

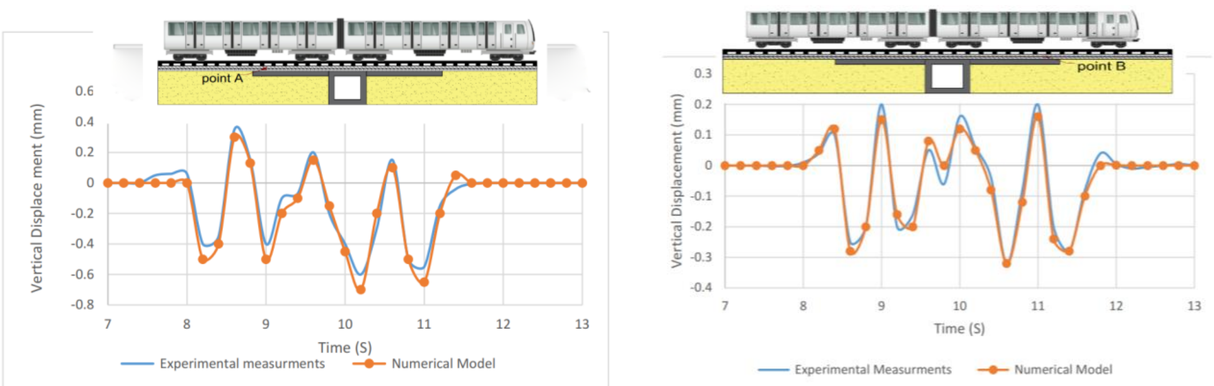
The HHTα-method is a general form of the Newmark method [23]and has a Controllable numerical damping effect. The damping effects in time history analysis are applied to the damping matrix in the following **Eq. (8)**:

$$C = \propto_j^e M_j^e + \beta_j^e K_j^e + B \tag{8}$$

$\propto_j^e$ = Mass proportional damping coefficient for j[th] element
M_j^e = Mass matrix of j[th] element
β_j^e = Stiffness proportional damping coefficient for j[th] element
K_j^e = Stiffness matrix due to material nonlinearity
B = Damping matrix due to damping element (damper)

Geometric damping is the soil damping which has been caused by the waves' radiation into the distant field, it only has a small impact on the outcomes.

A detailed experimental program was conducted using accelerometers and geophones to measure the displacement in the field [20]. A comparison of the results from the numerical model with the experimental data from dynamic measurements necessitates extensive processing and model updating
to yield an accurate model. **Figure 9** compares experimental and numerical results at two separate locations: one inside the ballast (point A) and the other inside the embankment (point B). The results were consistent with a train model of Sprinter T1 [20] traveling at 96 km/h. Results show a decent level of agreement. Both the displacement pattern and the amplitudes' form are comparable.



(a) (b)

Fig. 9 Vertical displacement measurement at (a) ballast (Point A) and (b) Embankment (Point B)

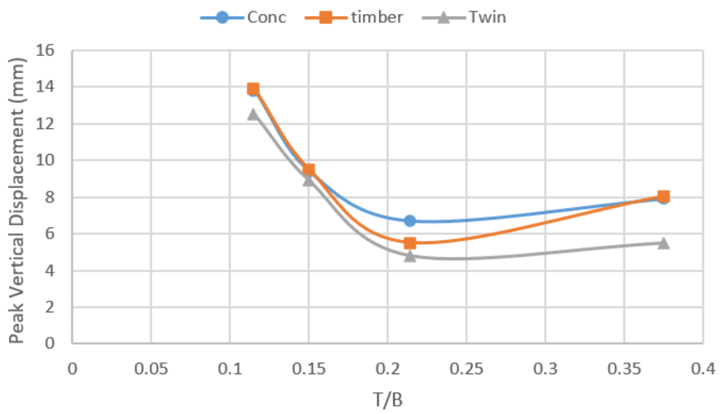
Results

The validated model was used to proceed with a parametric study to investigate the impact of culvert slabs' stiffness on soil dynamic behavior under different sleeper types. The stiffness of slabs is represented by the thickness-to-length ratio T/B. The soil dynamic response is observed by evaluating peak vertical displacement, peak shear stress, and peak vertical acceleration at three different locations the bottom of the ballast under the rail, the external edge of supporting the slab, and the left side of the culvert base.

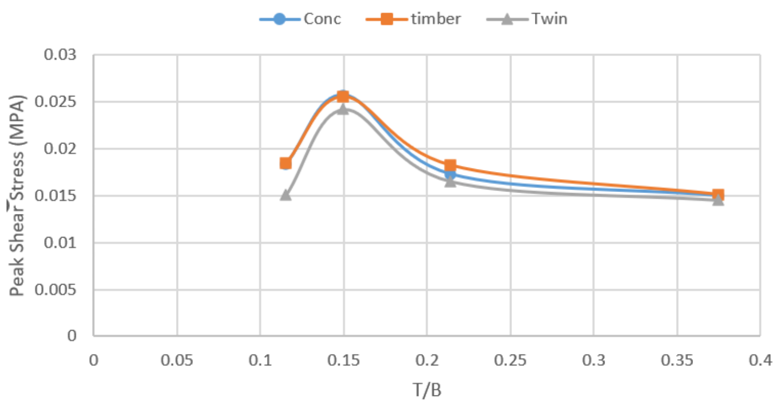
The dynamic response features were monitored under ballast/rail connection as demonstrated in **Figure 10**. Nearly, similar behavior at this connection was observed under the three sleepers. This can be attributed to the equal surface area of the contact zone beneath each type of sleepers especially concerning the relative stiffness between ballast and different sleeper types. It is worth to mention that this pattern is in a very good agreement with J. Real Et al.[24] .

As shown in **Figure 10 (a)** the peak vertical displacement slightly decreased by 60.4%, 51.5%, and 61.6% until the T/B ratio increased to 0.214, then significantly increased by 31.7%, 15.2%, and 12.7% for timber, concrete, and twin-block respectively. Twin block sleeper helps to achieve minimum peak vertical displacement regardless stiffness of culvert slabs. Concrete and timber sleepers mostly have the same peak displacement for different T/B ratios; however, the twin-block sleeper has a minimum peak displacement reduction of 30.4% compared to other types. Finally, it is noticed that the minimum peak vertical displacement was achieved at 0.214 T/B ratio under all sleeper types.

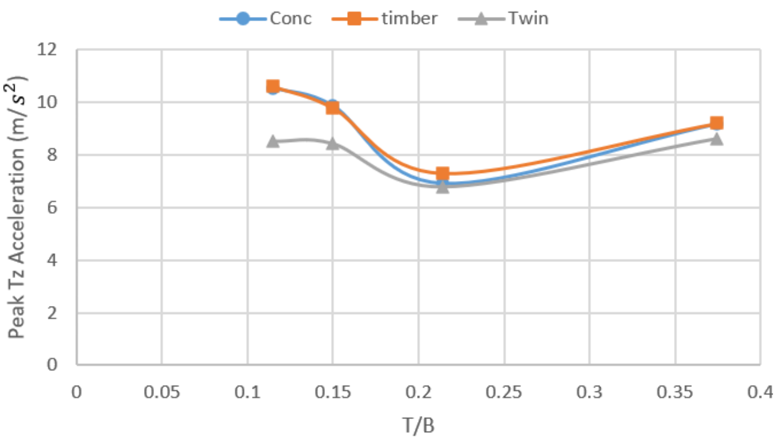
The most critical shear stress was generated at 0.15 T/B. It could be observed that when T/B increased from 0.115 to 0.15, a significant raise was observed in the peak shear stress by about 27.9%, 28.5% and 37.8% for timber, concrete, and twin-block respectively. Then, peak shear stress decreased by about 41.0% under all sleeper types until T/B ratio reached 0.25. Using any type of sleepers over a culvert with a T/B ratio larger than 0.25 does not affect peak shear stress as shown in **Figure 10 (b)**. A negligible difference is noticed in the peak vertical acceleration under both concrete and timber sleepers. Peak vertical acceleration decreased clearly by 31.2%, 20.4% and 34.5% until T/B ratio increases to 0.214, then increased by 20.7%, 24.8%, and 20.4% for timber, concrete, and twin-block respectively. The peak vertical acceleration under a twin-block sleeper showed a smaller value than other types. (**Figure 10 (c)**).



(a) Peak vertical displacement



(b) Peak shear stress

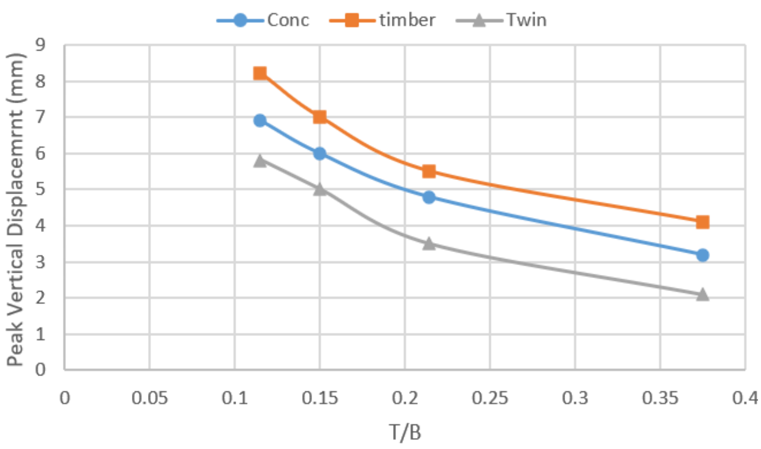


(c) Peak vertical Acceleration

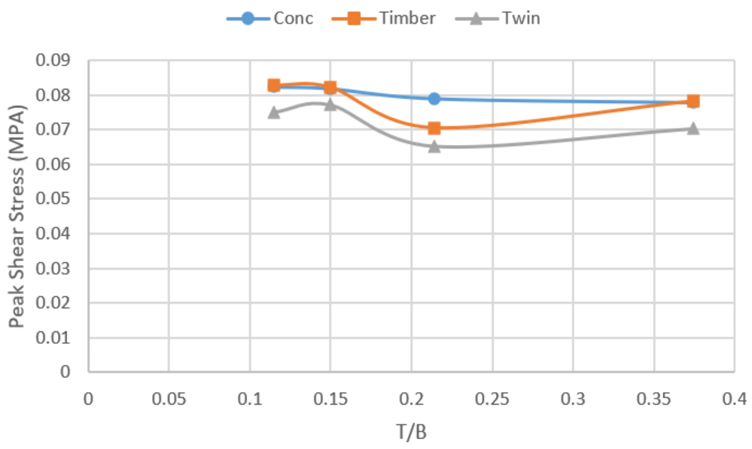
Fig. 10 Effect of slabs stiffness on soil dynamic response under ballast/rail connection with different types of sleepers

The dynamic response of the soil was monitored at the supporting slab edge as illustrated in **Figure 11**. A clear inverse relationship is shown in **Figure 11 (a)** between the peak vertical displacement and the stiffness of the culvert slab under all types of sleepers. Vertical displacements significantly decreased by about 50.0%, 53.6%, and 63.8% for timber, concrete, and twin-block, respectively, with an increase in the T/B ratio from 0.115 to 0.375. The twin-block sleeper caused the minimum value of vertical displacement which decreased by 48.8% at 0.375 T/B compared with other sleepers. A slight change in peak shear stress was observed with increasing T/B ratio of the slab stiffness. When T/B increased from 0.15 to 0.214, the peak shear stress decreased negligibly by 5.51% and 6.39% for timber and twin-block respectively. Regardless of slab stiffness, shear stresses under concrete sleepers were not affected as illustrated in **Figure 11 (b)**.

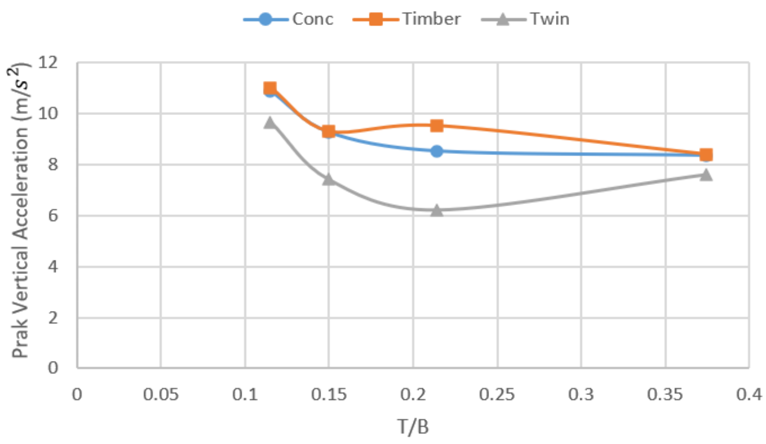
There is a similarity in peak vertical acceleration under both timber and concrete sleepers showing an inverse relationship with the slab stiffness. shear stresses were reduced significantly by 13.7%, 21.7%, and 35.5% for timber, concrete, and twin-block, respectively, until T/B ratio reached 0.214. The least dynamic response was generated under the twin-block sleeper compared to other types where vertical accelerations were reduced by 12.2% at 0.375 T/B ratio and 35.5% at 0.214 T/B ratio which is shown in **Figure 11 (c)**.



(a) Peak Vertical Displacement



(b) Peak Shear Stress

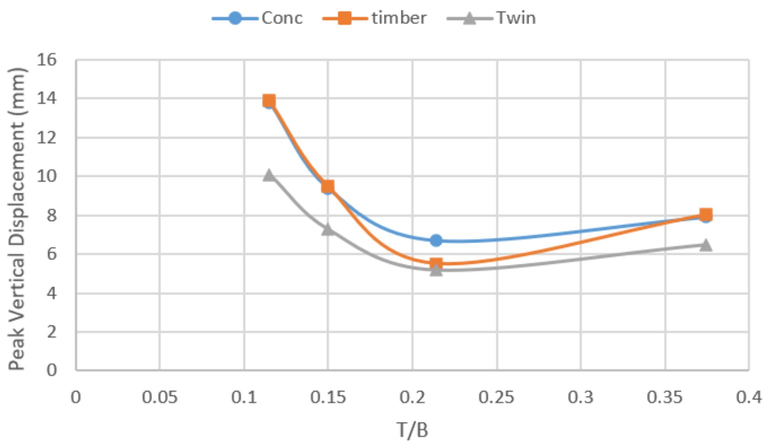


(c) Peak Vertical Acceleration

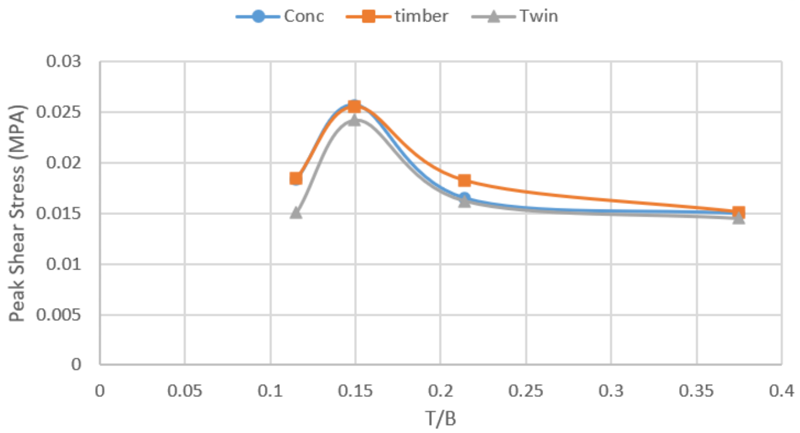
Fig. 11 The effect of slabs stiffness on soil dynamic response at the supporting slab edge with different types of sleepers

The dynamic response is monitored at the culvert base. As shown in **Figure 12 (a),** the peak vertical displacement slightly decreased by 60.4%, 51.5%, and 48.5% for timber, concrete, and twin-block respectively until the T/B ratio increased to 0.214 then significantly increased by about 31.51%, 15.19% and 20.00% for timber, concrete, and twin-block respectively. Twin block sleeper can result in the minimum peak vertical displacement regardless stiffness of culvert slabs. Concrete and timber sleepers mostly have the same peak displacement for different T/B ratios of culvert slab; however, the twin-block sleeper caused the minimum peak displacement reduction of 17.7% compared to other types. It can be noticed that the minimum peak vertical displacement was achieved at 0.214 T/B ratio under all sleeper types.

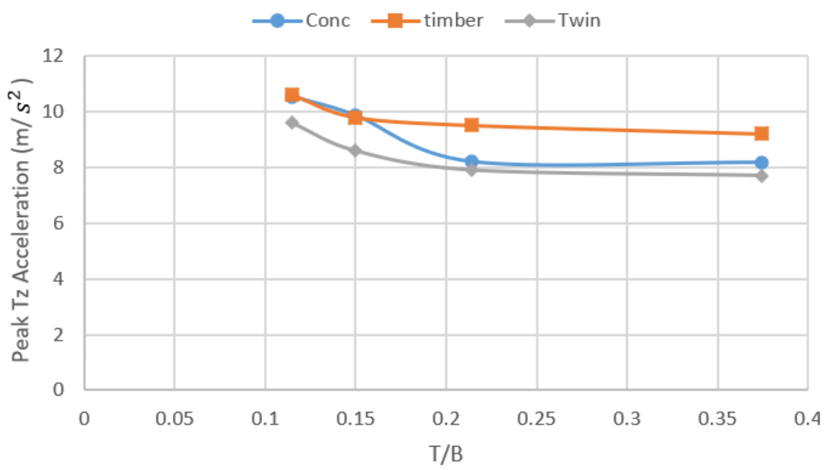
On increasing T/B ratio from 0.115 to 0.15, a significant increase was observed in the peak shear stress by about 26.8%, 25.5%, and 32.8% for timber, concrete, and twin-block respectively. Then, peak shear stress decreased by about 33.8% in all sleeper types until T/B ratio of 0.25. Using any type of sleepers over a culvert slab with a T/B ratio larger than 0.25 does not affect peak shear stress. Twin-block sleeper has showed a slight decreased value than other types as shown in **Figure 12 (b)**. With increasing T/B ratio of the slab stiffness, a minor change in the peak vertical acceleration was observed. When T/B increased from 0.115 to 0.214, the peak vertical acceleration was decreased negligibly by 10.4%, 22.2%, and 17.7% for timber, concrete, and twin-block respectively. Continuing its good performance, the twin-block sleeper could decrease the vertical acceleration by 9.4% to 16.8% compared to other sleeper types as demonstrated in **Figure 12 (c).**



(a) Peak Vertical Displacement



(b) Peak Shear Stress



(c) Peak Vertical Acceleration

Fig. 12 Effect of slab stiffness on soil dynamic response at the culvert base for different types of sleepers

Conclusion

This research aims to contribute to a better understanding of the interaction between railway superstructures at transition zones and the soil, which can enhance design codes and maintenance practices. A validated model was used to proceed with a parametric study to investigate the impact of culvert slabs stiffness on the soil dynamic behavior under different sleeper types. Based on the analysis of results the following conclusions were extracted:

1. Using twin-block sleepers is an optimum solution compared to concrete or timber sleepers where it generated the least peak vertical displacement, peak shear stress, and peak vertical acceleration through the soil section. This advantage in the dynamic response was observed in all culvert cases with different slab stiffness's.
2. Both concrete and timber sleepers showed similar results in soil dynamic response at the transition zone.
3. Increasing the culvert slab stiffness reduces the induced peak vertical displacement through the soil section. Peak vertical displacement was reduced by 62% using 0.214 T/B and by 64% using 0.375 T/B.
4. Under the ballast/rail connection and the culvert base, peak shear stress has increased by 38% with slab stiffness of 0.15 T/B; then it decreased by 41% at 0.214 T/B. After 0.25 T/B, it is noticed that increasing the slab stiffness of the culvert has no effect on the generated peak shear stress due to railway loads.
5. Increasing the slab stiffness has a negligible impact on the peak shear stress at the supporting slab edge.
6. Under both ballast/rail connection and supporting slab edge, peak vertical acceleration has increased by 35% at 0.214 T/B slab stiffness, then it decreased by 36% at 0.375 T/B. At the culvert base, peak vertical acceleration showed negligible effect with increasing slab stiffness.

REFERENCES

[1] Konstantinos Giannakos, and Andreas Loizos (2010), Evaluation of actions on concrete sleepers as design loads – influence of fastenings, DOI: 10.1080/10298430903402161

[2] JICA (2012) Japan International Cooperation Agency, Mints–Misr National Transport. The comprehensive study on the master plan for the nationwide transport system in the Arab Republic of Egypt, Technical Report 2, railway sector.

[3] Minister of Transport Speech during the General Session of the House of Representatives on Railways Projects, https://www.enr.gov.eg/En/NewsDetails.aspx?NewsID=1223, 2021

[4] Hőlscher, P. and P. Meijers (2007). Literature study of knowledge and experience of transition zones. Technical report, GeoDelft

[5] Roberto Sanudo ˜ Ortega a,*, Joao Pombo, Stefano Ricci, Marina Miranda (2021) The importance of sleepers spacing in railways, https://doi.org/10.1016/j.conbuildmat.2021.124326

[6] Omar Mohamed, Mohamed Nour, Iman Elazizy, Mona A. Hagras (2022)" Computing Cost and Time Contingency for Box Culverts Construction Projects Using Integrated Risk Management Technique DOI: 10.35940/ijeat. E3536.0611522

[7] Akshay Sakhare, Hafsa Farooq, Sanjay Nimbalkar, and Goudappa R. Dodagoudar (2022). Dynamic Behavior of the Transition Zone of an Integral Abutment Bridge https://doi.org/10.3390/su14074118

[8] João Manuel de Oliveira Barbosa, Andrei B. Faragau, Karel N. van Dalen (2021), A lattice model for transition zones in ballasted railway tracks https://doi.org/10.1016/j.jsv.2020.115840

[9] Zigang Xu, Xiuli Du, Chengshun Xu, Hong Hao, Kaiming Bia, Jiawei Jiang (2019), Numerical research on seismic response characteristics of shallow buried rectangular underground structure https://doi.org/10.1016/j.soildyn.2018.10.030

[10] Anonymous, available at (25.07.2023): https://www.visitsydneyaustralia.com.au/railwaybridges.html

[11] Damian Beben, (2014) Corrugated Steel Plate Culvert Response to Service Train Loads, DOI:10.1061/(ASCE)CF.1943-5509.0000422.

[12] Robert H. Crawford, (2009) Greenhouse Gas Emissions Embodied in Reinforced Concrete and Timber Railway Sleepers, DOI: 10.1021/es8023836

[13] A. Manalo, T. Aravinthan, W. Karunasena, and A. Ticoalu (2010) A review of alternative materials for replacing existing timber sleepers, Compos. Struct., https://doi.org/10.1016/j.compstruct.2009.08.046

[14] W. Ferdous, A. Manalo, G. Van Erp, T. Aravinthan, S. Kaewunruen, and A. Remennikov (2015) Composite railway sleepers: Recent developments, challenges and future prospects, https://doi.org/10.1016/j.compstruct.2015.08.058
[15] Esveld, C. (2001). Modern Railway Track-Second Edition. MRT Productions
[16] Jabbar Ali Zakeri, Hamid Hassanrezaei (2020), “Experimental Investigation on Effect of Winged Sleeper on Lateral Resistance of Ballasted Track”, Doi: 10.24200/sci.2020.53320.3184
[17] E. Ferro, J. Harkness, L. Le Pen (2020) The influence of sleeper material characteristics on railway track behaviour: concrete vs composite sleeper, https://doi.org/10.1016/j.trgeo.2020.100348
[18] Taufan Abadi, Louis Le Pen, Antonis Zervos, and William Powrie (2019) “Effect of Sleeper Interventions on Railway Track Performance” DOI:10.1061/(ASCE)GT.1943-5606.0002209
[19] Anonymous, available at (25.07.2023): https://www.stantonprecast.co.uk/rail-products/vibration-mitigationsleepers-bearers/
[20] Bruno Zuada Coelho (2011) Dynamics of railway transition zones in soft soils. DOI: 10.13140/RG.2.1.4355.2486
[21] Manual of Midas GTS NX Software
[22] H.M Hilber, T.J.R Hughes, and R.L. Taylor (1977) Improves Numerical Dissipation for Time Integration Algorithms in Structural Dynamics, https://doi.org/10.1002/eqe.4290050306
[23] M. Newmark (1959) A Method of Computation for Structural Dynamics, https://doi.org/10.1061/JMCEA3.0000098
[24] J. Real, Clara Zamorano, Clara Zamorano, T. Asensio, Laura Montalbán-Domingo(2014) Comparison of the effect of different sleeper typologies and track layout on railway vibrations DOI: 10.1590/S1679-78252014001200007