American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-6, Issue-7, pp-280-287
www.ajer.org
Research Paper
Open Access

Mechanics Calculation of Asphalt Concrete Track-substructure Layer and Comparisons

Mouhamed Bayane Bouraima, Enhui Yang, Yanjun Qiu
School of Civil Engineering Southwest Jiaotong University, Highway Engineering Key Laboratory of Sichuan Province, Chengdu, Sichuan 610031, China.
Corresponding Author: Mouhamed Bayane Bouraima

ABSTRACT: *Asphalt concrete mix with the merits of good bearing capacity, low water permeability, shock absorption, excellent strength, noise reduction and easy construction is an important option of high speed railway substructures. In recent years, China has witness a rapid grow in the high speed railway sector resulting in railway fatigue, drainage and settlement issues in the loading bearing infrastructure of tracks. Asphalt concrete has been used in the railway infrastructure of Chinese high speed railway. On the basis of finite element method, mechanic responses of asphalt concrete underlayment (ACRS-1 type) and an ordinary slab structure based on mechanistic models were analyzed using both static and dynamic loads. The results show that the stress at the bottom of the asphalt concrete foundation under the ACRS-1 structure is very small, and will not exceed the bearing capacity of the asphalt concrete which is the allowable strength. Comparison of the two kinds of track infrastructures indicates that asphalt concrete (ACRS-1) can reduce the vertical dynamic deformation of the track structure to a certain extent. Asphalt concrete reinforced subgrade bed structure can reduce the vertical vibration of track structure. The reduction of the amplitude of the acceleration can reduce the noise ability.*

Keywords: *Mechanical response, finite element method, Slab track, asphalt concrete underlayment.*

Date of Submission: 13 -07-2017 Date of acceptance: 28-07-2017

I. INTRODUCTION

During the last two decades, China's transportation infrastructure is advancing quickly with rapid economic development and urbanization. According to China's government plan, the total length of railway will be about 100,000 km length by end of 2020 year, containing 16,000 km length of high speed railway. Good stability and high performance materials are required in the load-bearing infrastructure to support uninterrupted high-speed trains at required safety level. These materials should have the ability of reducing vibration and noise of the infrastructure for trains operating at 350 km/h. Although new materials performance have been investigated to support high-speed rail slab tracks, many issues such as low level of vibration and noise and excellent drainage to reduce water damage still remain. Comparing to highway pavements where the Asphalt Concrete (AC) service life is about 15 to 20 years, the loading-bearing infrastructure for high-speed rail is designed for even more than 100 years based on Chinese Code for Design on Railway Subgrades (Ministry of Railway of People's Republic of China, 2005). The use of AC as a second layer to support the slab track, which directly interfaces with high-speed rails has been noticed in recent decades on many occasions around the world. Since AC can be used as alternatives materials to replace or partly replace the traditional railway concrete slab, subgrade and also for the waterproof layer on the surface, this paper presents the effect of dynamic and static loading effect and their comparison on the performance of two asphalt concrete underlayment (ACRS-1 type and ACRS-2 type) and an ordinary slab structure based on mechanistic models and finding the suitable structure required in high-speed rail infrastructures.

II. LITERATURE REVIEW

Since the opening of the world's first high speed railway in 1964, high speed railways have shown strong competitiveness among other modes of transport and are being developed primarily in Japan, Germany, France, China, the United States, Italy and others countries. The application of Asphalt concrete in many projects around the world has been noticed recently. In USA since the early 1980's, a 15 cm thickness of AC was primarily used for maintenance (cure-all) applications in existing tracks to improve track bed performance and for new track bed construction where the projected superior performance of asphalt track beds can be justified economically **(Read and Whiteoak, 2004).**

HMA underlayment has also been used during the rehabilitation or renewal of expensive special track works such as railroads crossings and crossovers and turnouts. The added support by its layer has reduced maintenance costs and improved performance **(Rose, 1992)**. In addition, it was successfully placed under a raised track without removing the rail and ties on the Santa Fe Railway's mainline near Cassoday, Kansas in 1986 (Railway Track & Structures, 1987). **(Talbolt, 1919)** has carried both theoretical and field test research in USA. Efforts have been made by (**Rose et al, 1984)** to develop HMA as premium quality integral track bed material during the late 1960's. In the early 1980s, they also renew interest by using HMA in the track structure as support mat in place of conventional all-granular sub ballast or geotextile (**Brown, 1998**). **Dingqing et al**., 2001 have tested the application of Hot Mix Asphalt over a soft subgrade under 39-ton axle loads. The purpose of the test is to reduce the traffic load induced stresses to the subgrade and to provide waterproofing layer over underlying soil by using HMA underlayment. They evaluated the performance of the test track in terms of track geometry, degradation with traffic as well as the amount of track modulus increase compare to conventional granular layer construction. The results of the test show that the HMA underlayment has significantly increased the track modulus from the 18-inch granular track with an average track modulus of 2,000Ibs/in/in. In the same time, the measured subgrade stresses were lower for the asphalt track bed than for the 18-inch granular track. Early studies also were conducted at developing an overlayment system different to that of an underlayment except no ballast was put between the ties and HMA mats (**Rose et al, 1983**). Tests and observations have determined the site-specific benefits provided by HMA underlayment which are considered to impact ideal properties to the track system to maximize the operational efficiency **(Rose & Hensley, 1991; Rose, 1998**). Two kinds of railway HMA were used for heavy loading railway and high-speed railway in USA. The first one was the underlayment, and the other one was for the overlayment of railway. The results from the research showed that both structures were useful for improving the stress distribution and good water performance **(Rose &Anderson, 2006)**.

Two types of AC structures with 50-80 and 150-200 mm in thickness respectively were used in Japan railway for reinforcement of the subgrade surface of railway ballast in 1978 **(Japanese National Railway Institute, geotechnical structure design standards and commentary 1982)**. They were used to reinforce the subgrade surface of railway ballast. The research results show that the fluctuation of water content in the subgrade has been reduced and the load distribution has been improved due to the AC reinforced subgrade surface.

Germany has focused on using GETRAC (**Ren et al., 2008**), a ballastless railway with concrete track slab on the top. The asphalt concrete was constructed between the track slabs with the base layer, the thickness of which was about 35 cm **(Lechner, 2005).**

France has adopted the use of asphalt concrete for the underlayment of the TGV (Train a Grande Vitesse) high-speed railway was the ballast railway. The asphalt concrete layer was constructed as an adjustment layer between the subgrade layer and ballast layer (**Iwnicki, 2009; Robinet and Cuccaroni, 2010**). A test section of about 3km length was built in 1999 in Netherlands, in which the asphalt concrete was placed under the rail track slab. It was called ERIA (Embedded Rail in Asphalt) **(Huurman et al., 2003).** As attempt to evaluate the possible benefits of using bituminous sub-ballast in Spain, a study carried out by the authors **(CENIT 2005)** investigated the geometric quality deterioration records on sections with and without bituminous sub-ballast on the Rome-Florence high speed line. Results indicate a slight positive effect of using it in the maintenance needs at transition section (bridge-embankment). Bituminous sub-ballast can also play an important part related to dynamic behavior of track at high-speed and very high speeds which is one of the major factors of the track settlements (Lopez et al., 2004). In China, the use of Railway Asphalt Concrete layers (RAC) has been investigated by scholars for use in asphaltum beds, asphalt mortar layers, and asphalt emulsion-treated cement mortar layers as reinforcing materials in recent decades **(Xu and Liu 1980; Huang and Sun 1991; Liu 1994).** In addition, the research team at Southwest Jiaotong University (SWJTU) conducted systematic research on RAC infrastructure for the design of the first AC application for high-speed rail in China for Wuguang and Jinghu high-speed railway, with the original purpose being to provide a waterproof surface **(Qiu and Wei 2008; Qiu et al., 2011)**. Through numerical modeling, this paper presents the mechanic response of one asphalt concrete underlayment (ACRS-1 type a) and an ordinary slab structure using dynamic and static loads.

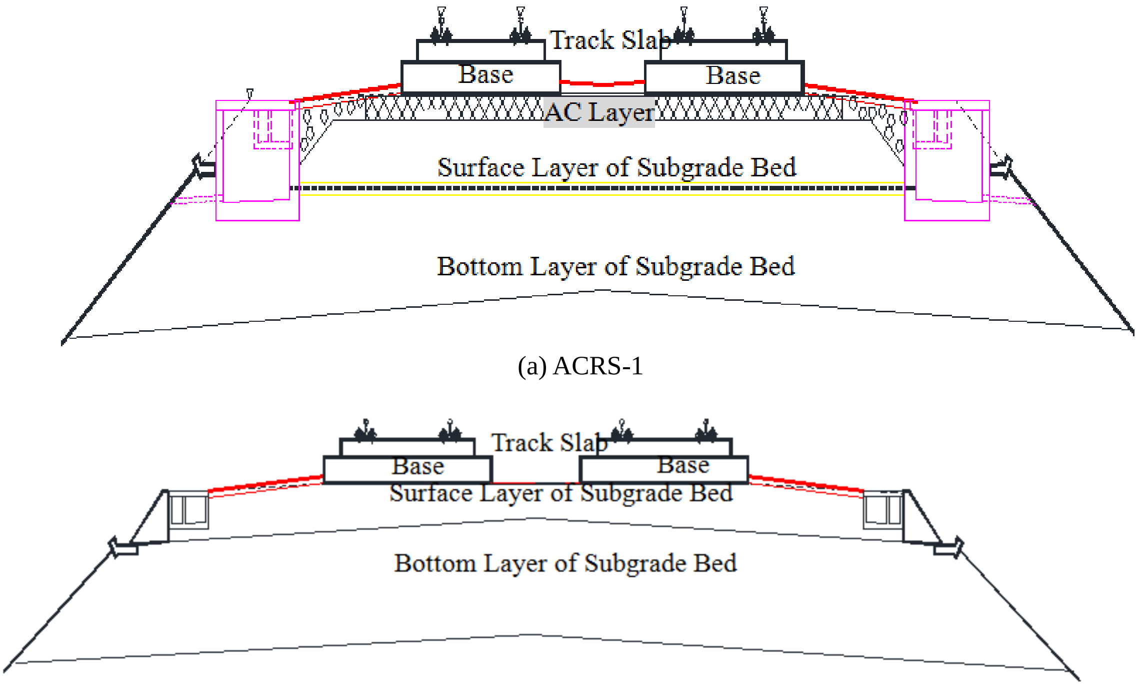
III. NUMERICAL MODELING

The large Finite Element Method is used in the study to demonstrate modeling performances of different implementations of AC for railway infrastructure. Two structures have been used in this research: the Asphalt Concrete Railway Substructure (ACRS) used at SWJTU to partly replace the surface layer of subgrade bed

(ACRS-1) and the traditional slab track.

1) Modeling of applications

In this paper two different structures were used in the modeling process, as shown in Fig. 1 ,the first one is the ACRS-1 structure with the surface layer of subgrade partly replaced by the asphalt concrete layer and the second one is the traditional slab track used in Wuguang and Jinghu High-speed Railway. The geometric design data are shown in **Table 1**.



(a) ACRS-1

(b) Traditional Slab Track

Fig.1 Structure designed for high-speed railway

2) FEM calculation model

The numerical calculation is used considering two different structures. The first one is the ACRS-1 structure with the surface layer of subgrade partly replaced by the asphalt concrete layer, the second one is the traditional Slab Track used in Wuguang and Jinghu High-speed Railway. The large Finite Element Method (FEM) software ABAQUS was used in the study to demonstrate modeling performance of the implementation of AC for railway infrastructure compare to the traditional slab track. The stress, displacement and acceleration of the asphalt concrete structural layer and slab track are calculated under the influence of static and dynamic load, to provide theoretical guidance for the design of the basic structure of asphalt concrete under the rail. At the first stage, dynamic response of the two structures is analyzed under the speed of 200km/h (design speed of the intercity railway) and then compared the mechanics response under static load. The FEM modeling process of the two structures is shown in Fig. 2. The boundary condition of the bottom is constrained for the deformation of all directions. The boundary condition of the longitudinal section is constrained for the rotational and vertical deformation. The generated mesh is consisting of 8 nodes reduced integration unit C3D8R, the type of which can get high accuracy with smaller computation cost. The static loading is controlled at about 25 t for each axis of train. There are 8 wheels loads for the double-line railway with 125 KN in weight for each wheel. Usually, when considering the design load of railway subgrade, the static load and dynamic load are simplified as static load treatment in calculation. However, the design of high speed railway subgrade cannot be simply treated as static load. Dynamic analysis must be performed. The calculation of subgrade dynamic load can be referred to the ministry of railways academy which is the relationship between stress and speed

$$\sigma d = 0.26 \times P \times (1 + aV)$$

where:

σd -- Design of subgrade dynamic stress amplitude (kPa).

P - Vehicle static axle load (t).

a -high speed railway: no joint railway 0.003 ; quasi high speed railway、no joint railway: 0.004

V - The train speed (km/h).

3) Numerical parameters

Table 1 shows the geometric design and materials parameters of each structure. For consideration of high temperatures in the summer, the elasticity modulus of railway asphalt concrete was selected at relatively low value. The other material parameters were all from the asphalt pavement specifications and previous studies for highway applications.

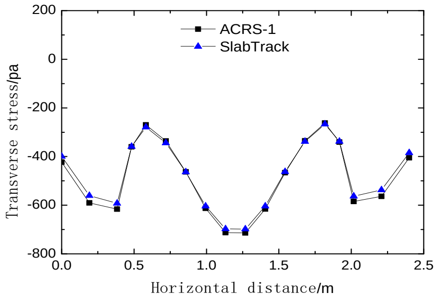
Table 1 Calculation parameters of the whole structure model of asphalt concrete

Structure	Geometry(m)		Material	Material parameters			
				modulus of elasticity E/Mpa	Poisson's ratio	Unit weight /kg/m3	damping ratio
Slab	Width: 2.4 Thickness: 0.19		C60	3.6×10^4	0.16	2450	0.03
Base	ACRS-1	Width: 3.0 Thickness:0.3	C40	3.25×104	0.167	2450	0.03
ACRS	ACRS-1	Width: 8.8 Thickness:0.2	RAC-25	370（static） 200（dynamic）	0.45	2360	0.055
Surface layer of Subgrade Bed	ACRS-1	Width: 13.2 Thickness:0.2	Graded gravel	200（static） 150（dynamic）	0.3	2000	0.045
Bottom layer of subgrade surface	Width:13.2 Thickness: 2.3		A、B set gravel	160（static） 120（dynamic）	0.35	1900	0.039
Sub-Bed	Width: 24.6 Thickness : 3.0		Improved soil	110（static） 60（dynamic）	0.35	1900	0.039

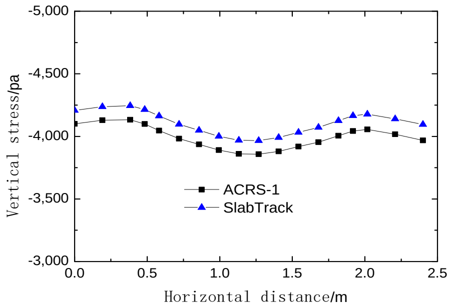
According to the relevant literature **(Gourvish, 2010)**, when the dynamic analysis is performed, the material should consider the damping ratio. This study considers Rayleigh damping with related coefficient alpha =0.930, beta =0.0027 values for the general concrete, and alpha =0.0410, beta =0.0061 for granular material.

IV. NUMERICAL RESULTS

As shown in Fig. 2, the transverse stress at the bottom of the Slab Track of the two structures was tensile stress, which was adverse for concrete slab. The vertical stress at the bottom of the track slab for the two structures was about 4.1 kPa under loading position with ACRS-1 which is relatively smaller. In general, the stress level of the ACRS-1 structure is 3% -4% lower than that of the slab track structure (static loads).



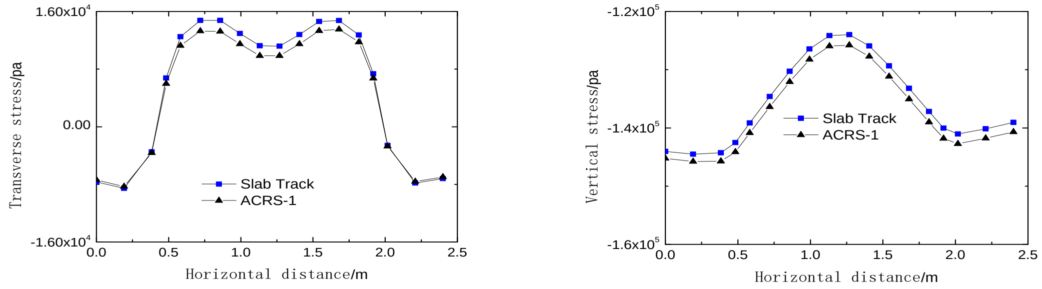
(1) Transverse stress



(2) Vertical stress

Fig 2. Stress at the bottom of track slab for different structure types (static)

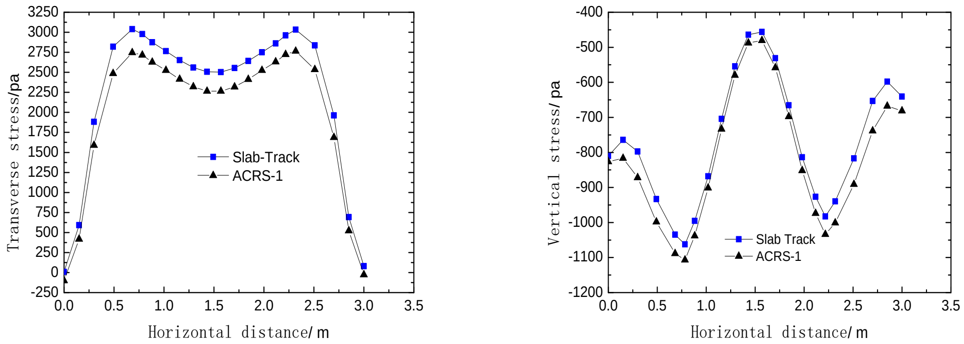
The curve in Fig. 3 shows that under the action of dynamic load, the variation trend of transverse and vertical stresses along the horizontal direction is similar to that of static force but the difference is that the stresses responses of ACRS-1 and slab track structures under static loading are negative indicating that the bottom of the track is under tension which result in the tension of the whole slab track at its bottom. However, for dynamic effects the response is tensioned except that there is compressional transverse stress on either side of the track plate. This is because the overall modulus of the two structures is greater which leads to a better resistance and supporting effect on the upper. At the same time, the difference between these two structures lies in the fact that the maximum tensile stress of the ACRS-1 is smaller than that of the slab track about 11 %(dynamic loads). The structure of ACRS-1 set asphalt concrete as the surface layer of the reinforcing subgrade bed which is like treating the lower structure as a "spring". Reinforced the subgrade bed means an increase of the stiffness of the "spring", thereby enhancing the resilience of the lower structure. Therefore, although the transverse dynamic stress at the bottom of the track slab is increased, the whole structure is more stable.



(1) Transverse stress (2) Vertical stress

Fig 3. Stress at the bottom of track slab for different structure types (dynamic)

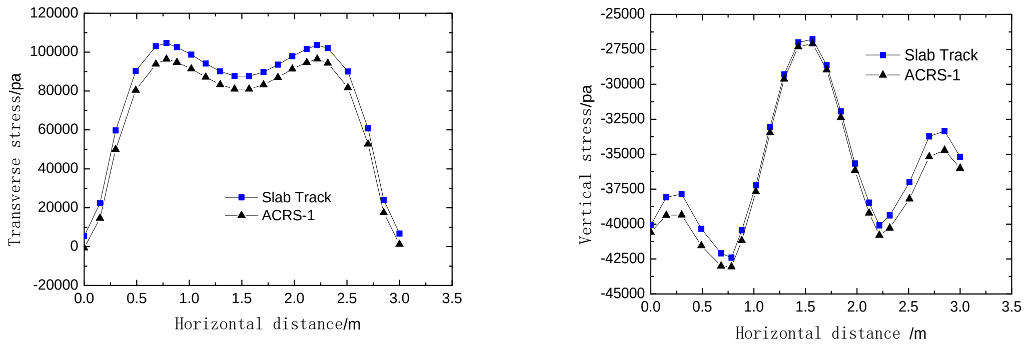
The curves of stress at the bottom of two kinds of structures (Fig. 4 (1)) along the horizontal path show that the transverse stress at the edge of the foundation plate of the ACRS-1 and slab track structures are similar with the difference that the internal stress of the ACRS-1 structure is smaller than that of the Slab Track structure about 250 Pa. The vertical stress of ACRS-1 and slab track structures at the bottom of base layer under static load (Fig. 4 (2)) was tensional stress and was approximately 1000Pa on the edge of the base plate and suddenly reduces to 450 Pa inside the plate; the uneven stress changes in the interlayer will greatly affect the long-term performance of the track structure. The vertical stress at the bottom of base for ACRS-1 is smaller than that of the Slab Track.



(1) Transverse stress (2) Vertical stress

Fig 4. Stress at the bottom of the base layer for different structure types (static)

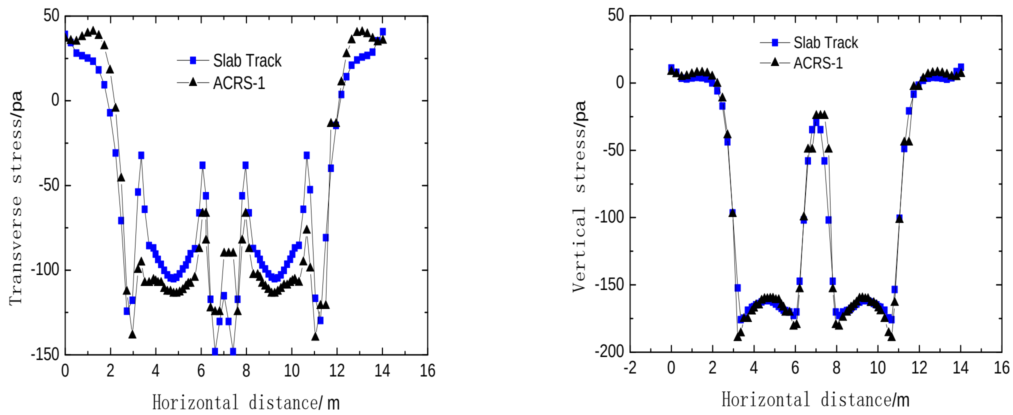
Analysis of the curve under dynamic load in Fig. 5 is similar to the analysis of static law because the asphalt concrete foundation plate is used as the direct support layer and the improvement of the internal stress of the track structure is also obvious from the dynamic analysis. For the ACRS-1 and Slab track structures, the bottom of the base layer is specially subjected to transverse compressive stress of about 96.4 kPa to 104.7 kPa (ACRS-1 structure is about 8 kPa smaller than slab track structure) and vertical tensile stress of 25 kPa to 42 kPa with the stress fluctuation which is obvious.



(1) Transverse stress (2) Vertical stress

Fig 5. Stress at the bottom of the base layer for different structure types (dynamic)

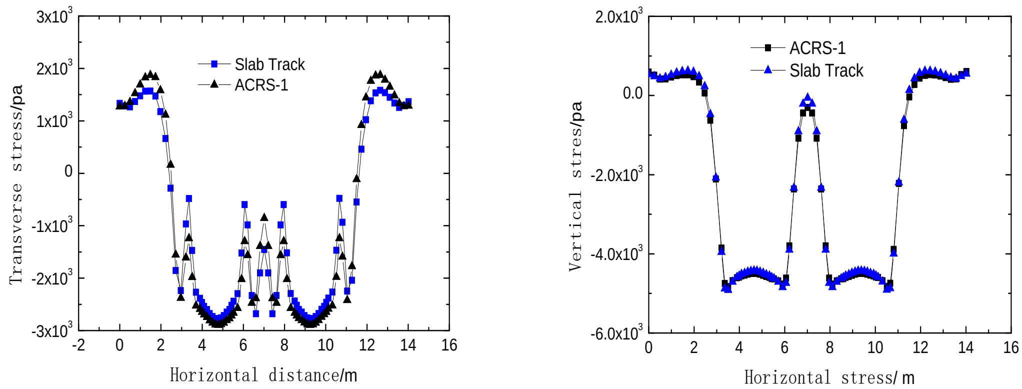
As shown in Fig. 6, the stress level at the bottom of the subgrade surface layer for ACRS-1 was generally smaller than that of the slab Track structure, which indicates that the surface stress of the subgrade bed has been improved after the application of asphalt concrete.



(1) Transverse stress (2) Vertical stress

Fig 6. Stress at the bottom of subgrade surface layer for different structure types (static load)

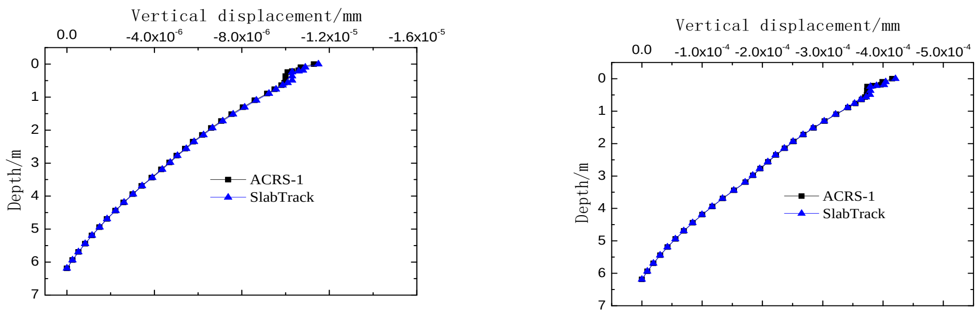
From the analysis of the curve in Fig. 7, it can be seen that the stress trend at the surface of the subgrade surface under dynamic and static loading analysis basically the same, but the overall stress level under dynamic loading increased by about 20 times.



(1) Transverse stress (2) Vertical stress

Fig 7. Stress at the bottom of subgrade surface layer for the different structure types (dynamic load)

The curves in Fig. 8 show that: (1) the deformation of the two structures is very small under both static and dynamic loading; the trend of vertical deformation decreases rapidly with the increase of depth. (2) Along depth of the structures, there is no slight difference in vertical displacement between ACRS-1 and Slab Track structures with ACRS-1 which value was the smallest.



(1) the role of static (2) dynamic role

Fig 8. Curves of vertical deformation versus depth for the different structure types

As can be seen from Fig. 9, the time history curve of vertical deformation at the center point of the track plate load was changing for the two structures and reaches the maximum vertical deformation at the moment of 0.081s. The vertical displacement in ACRS-1 is a little smaller than that of the slab track.

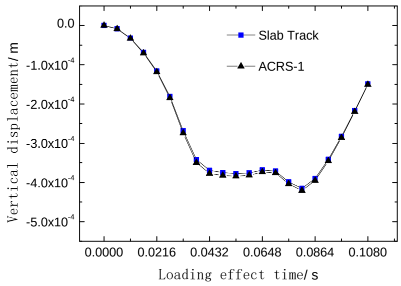
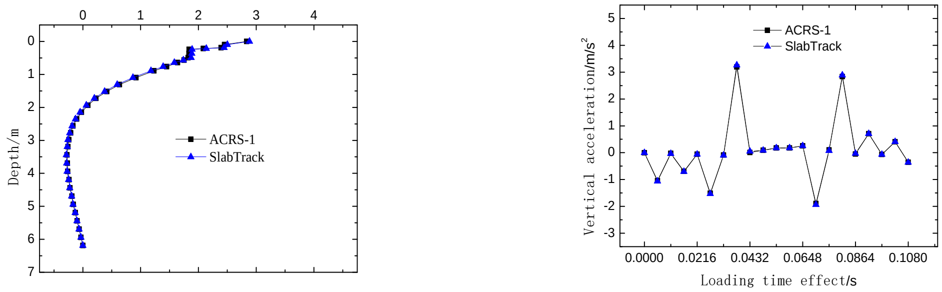


Fig 9. Time-history curve of vertical deformation of the load point of a track plate for the different structure types

As shown in Fig. 10, the vertical acceleration of the two structures along the depth of the load path and the loading point of the track plate decreases rapidly along depth of 1m and the maximum vertical acceleration of the two structures is around 2.8 m/s^2 with ACRS-1 which is slightly smaller; there is no change in the characteristics of these structures which is consistent with vertical deformation along depth changes in the range of 0.2-0.5m. It is concluded that the load depth range of 1m is the effective depth of vertical acceleration control and the vertical vibration of track structure has been reduced including the depth of track plate, CA mortar, rail base plate and the surface layer of the subgrade. Because of the role of track plate as the direct support structure of train load, it is not appropriate to choose the flexible material. However CA mortar is a kind of technology which is used to adjust the geometric shape and vibration damping structure layer, but its development trend is to increase strength while increasing flexibility of the track base plate and the surface layer of subgrade in the dynamic load range even both the structure and materials can be diversified.



(1) Vertical acceleration A2 along the depth of the load path (2) Vertical acceleration A2 of the load point of the track plate

Fig 10. Vertical acceleration VS. depth of the for the different structure types

V. CONCLUSIONS

Based on the comparative analysis of static and dynamic calculation of the structure of asphalt concrete railway substructure (ACRS-1) and traditional ballastless track, the following conclusions can be drawn:

- The ACRS-1 structure was useful for reducing the stresses under train loading for the railway infrastructure.

It has good ability to distribute the loads transmitted by passing trains.

- The structure of ACRS-1 can reduce the vertical displacement of the track structure to a certain extent. It has a better performance than the slab track. For example the vertical displacement of slab track is larger than that of the ACRS-1 structure, which is about 2.86mm.
- The structure of ACRS-1 to partly replace the surface layer of subgrade produces a smaller vertical acceleration compare to slab track. The reduction of the amplitude of the acceleration can reduce the noise ability to a certain extent.
- The variation trend of transverse and vertical stresses along the horizontal direction of static loading is similar to that of dynamic force. However the overall stress level under dynamic loading increased by about 20 times.

ACKNOWLEDGEMENTS

Funding for this research was supported by the National Natural Science Foundation of China (Grant N0 51308477), National Program on Key Basic Research Project (973 Program, 2013CB036204) and Fundamental Research Funds for the Central Universities (2682013BR030). The authors gratefully acknowledge the support.

REFERENCES

[1]. Brown, E. R, 1998. Use of Hot Mix Asphalt (HMA) in Railroad Construction. Proc., Roadbed Stabilization and Ballast Symposium, AREMA, Ypsilanti, Mich.
[2]. CENIT, 2005. Estudio sobre la viabilidad de incorporar capas de sub-balasto con material bituminoso en las lineas de alta velocidad en España -Fase 2. 252 pp. Conf. Report. Dic. 2005.
[3]. GOURVISH T, 2010. The High Speed Rail Revolution: History and Prospects [R]. HS2 Published on March. 11, 44 pages.
[4]. Huang Changsui, Sun Zhongzheng, 1991. Railway application and development of asphalt track bed [J]. Journal of Railway Engineering Society, (3):132-140.
[5]. Huurman M., Markine V, Man A, 2003. Design for Embedded Rail in Asphalt [C]. Proceedings of Railway Engineering-Conference, London, UK, 3rd-4th July 2002.ISBN 0-947644-49-0.
[6]. Iwnicki S, 2009. Future Trends in Railway Engineering [C]. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, , 23 (12) 2743-2750.
[7]. Japanese National Railway Institute, Translated by Raorong Chen, 1982. Geotechnical structure design standards and commentary [M. Beijing: China Railway Press.
[8]. Lechner B, 2005. Ballastless Tracks on Asphalts Pavements Design and Experiences in Germany [C]. Proceedings of the 7th International Conference on the Bearing Capacity of Roads, Railways and Airfields, Trondheim, 2729:5-20.
[9]. Li, D., J. Rose, and J. Lo Presti, 2001. Test of Hot-Mix Asphalt Trackbed over Soft Subgrade under Heavy Axle Loads. Technology Digest, Transportation Technology Center, Inc.
[10]. Liu Lianrong, 1994. Discussion on the high speed railway infrastructure types and reinforced foundation [J]. Railway Standard Design, (5):7-11.
[11]. Lopez Pita, A., P. F. Teixeira and F. Robusté, 2004. High Speed Track Deterioration: The Role of the Vertical Stiffness of the Track. Proc. Instn Mech.Engrs. Part F: Journal of Rail and Rapid Transit, Vol. 218, Issue 1, 2004, pp.3140.
[12]. Ministry of Railway of People's Republic of China. Code for design on subgrade of Railway, China Railway Publishing House, Beijing.
[13]. Qiu, Y.J., Fang, M.J., Zhang, X.J., and Wei, Y. X, 2011. Dynamic analysis of structural adaptively of ballastless track substructure of high-speed railway. J. Southwest Jiaotong Univ., 46(2), 183-188.
[14]. Qiu, Y.J., and Wei, Y. X, 2008. Mixing design and application of impermeable asphalt mixture in subgrade surface layer of ballastless railway track substructure. J. China Railway Soc., 30(5), 85-91.
[15]. Railway Track & Structures. Lift and Place for HMA. June 1987, pp. 24 -27.
[16]. Read J, Whiteoak D, 2004. The Shell Bitumen Handbook [M]. The 5th Edition, the Shell Bitumen Handbook.
[17]. Ren Juanjuan, Stephan Freudenstein, YANG Rongshan, LIU Xueyi, 2008. Structural features and application of German GETRAC ballastless track [J]. Chinese Railway, (4): 68-71.
[18]. Robinet, A., and Cuccaroni, A, 2010. Sub-ballast layer made of bituminous material. Proc., 7th World Congress on High-speed Rail, China Railway Press, Beijing, 727-730
[19]. Rose, J. G., et al, 1983. Hot Mix Asphalt Railroad Trackbed Construction and Performance. Research Report QIP 104-7/83, National Asphalt Pavement Assoc.
[20]. Rose, J. G., C. Lin, and V. P. Drnevich, 1984. Hot Mix Asphalt for Railroad Trackbeds Construction, Performance and Overview. Proc., Association of Asphalt Paving Technologists Technical Session, Vol. 53, pp. 19-50.
[21]. Rose, J. G., and M. J. Hensley, 1991. Performance of Hot-Mix-Asphalt Railway Trackbeds. In Transportation Research Record 1300, TRB, National Research Council, Washington, D.C., pp. 35-44
[22]. Rose, J. G, 1992. Turnout Rehabilitation with Bituminous Concrete Underlayment's. In Transportation Research Record 1341, TRB, National Research Council, Washington, D.C., pp. 75-82
[23]. Rose, J. G, 1998. Long-Term Performances, Tests and Evaluations of Asphalt Trackbeds. Presented at the AREMA Technical Conference, Chicago, Ill.
[24]. Rose J, ANDERSON, 2006. Long-Term Performance of Asphalt Underlayment Trackbeds for special Trackbed Applications [C]. American Railway Engineering and Maintenance-of-Way Assoc.2006 Ann.Conf.Proc, Louisville, K Y, 27pages.
[25]. TALBOT A N, 1919. Second progress report of the special committee to report on stress in railroad track. Proceeding of American Railway Engineering Association (AREA), pp. 297-453.
[26]. Xu Yan, Liu Jialin, 1980. The new asphalt track bed used for railway infrastructure [J]. Railway Engineering, (1):4-9.

Mouhamed Bayane Bouraima. "Mechanics Calculation of Asphalt Concrete Track-substructure Layer and Comparisons." American Journal of Engineering Research (AJER) 6.7 (2017): 280-287.