Effect of Constructing Canal in Embankments on Sand Flow through Railway Tracks in Desert Regions

Houshang Pakdel Samadi[1], Jabbar Ali Zakeri[2], Gholamreza Nabi Bidhendi[3],

Abstract

Entry of sand dunes into the railway tracks can result in sand deposition on tracks, railway obstruction, derailment, damage to track flexibility, and impairment of electrical signs and rail fleet. The approach of the present study is to keep the route open for sand pass. Therefore, it is aimed to investigate the strategies and solutions for reducing sand aggregation on railway tracks (including construction of sand passage canals through embankments and modification of the geometric form of the track sleeper humps) and to present an optimal design for the created canals in order to provide easy movement of the sands. The fluid analyses were performed in the relevant software (via numerical modeling) based on the maximum sand passage through canals, minimum subsidence of sand at entries, and minimum deposition of sand on slabs. In this regard, using the fluid mechanics principles (aerodynamics), the design requirements and limitations were taken into account; then, various distances of the canals from railway surface as well as various geometric forms of the hump, which had appropriate aerodynamic behaviors, were designed and simulated using **Rhino** software. Diameter of the canal was equal to 1.5 m and located at various distances (0-2 m) from the embankment surface. The designs were simulated in **Fluent** software. Results of the analyses on the canals indicated that the M4-P2 canal design (2m distance from the embankment and a hump with conic circular form and height of 20 cm ($M\text{-}C_{20}$) was the optimal one. Besides, it was shown that the circular-form cross-sections would remove the sands much faster than other studied forms.

Keywords: Slab track, sand dunes, sand-absorbing region, sand flow simulation, embankment.

Corresponding author E-mail: hppakdel@yahoo.com
[1] (Corresponding author), Ph.D. Candidate, Shakhespajouh Disaster Engineering Research Institute, Isfahan, Iran
[2] Professor, Department of Railway Engineering, Iran University of Science and Technology, Tehran, Iran
[3] Professor, Faculty of Environment, University if Tehran, Tehran, Iran

1. Introduction

Since movement of sand dunes is a great threat to the exploitation of railway industries and can cause crisis in the engaged tracks, it is necessary to take serious measures for preventing of such a crisis. The sands in dry deserts, in case of entry into the tracks in huge volumes, can slow down and, eventually, stop trains' movement also result in irrecoverable damage to the infrastructures. On this basis, in all the vulnerable countries, including Iran, it has been always attempted to find solutions for reducing the sand entry into and deposition on railway tracks through traditional methods such as planting trees, mulch-pouring, etc… as well as newer methods, namely, biological fixation techniques, modification of variants, leaving open the sand pass routes, etc… Therefore, both methods have been investigated in several studies in Iran. The issue that is studied in the present paper is one of the modern methods for leaving open the natural route of the sands pass. Previous studies have been focused on the effect of the use of increased sleeper height in railway deployment locations (use of hump design in railway deployment location) and concreting the railway tracks, instead of the use of ballast has been investigated, which have led to desirable results [Fathi, 2008, Zakeri, 2012, Zakeri, 2011].

Subsequent to the above-mentioned works, the present study is aimed to investigate the use of the design of canal construction within rail embankments along the sand-absorbing railway tracks considering the executive railway standards as well as aerodynamic conditions. In this design, the humped slab track is used simultaneously. In this study, by passing the sands with specified features and conditions (in accordance with the two-phase 3D model simulated in **Fluent** software), the sand subsidence rate within the canal is measured by changing the canal height from under the slab track. Since in all the considered modern methods, the main objective has been to leave open the sand pass route, the present study is aimed to find the best place for constructing the canal within the embankment so that, besides observing the economic and technical justification and safety principles, the minimum sand subsidence can be achieved by passing the same sand volume in all the models. In other words, a canal should be selected that can cause the maximum sand volume to pass. It is evident that achieving such an objective would lead to a considerable reduction in the critical status of the tracks, including track obstruction, train stop, and delay in cargo as well as passenger arrival.

2. Effect of Storm on Train Movement Systems and Comfort of Passengers and Train Personnel

More than 80% of the lands in our country are located in arid and semi-arid areas. Besides, according to the estimations, 20% of the lands, i.e. more than 32.6 million hectare, are desert. The effects of sand storm on passengers and train movement systems include reduced train speed, train stop, reduced loading capacity of the tracks, elongation of train movement tracks, probable derailment, contamination of the interior space of wagons, necessity of regular cleaning, lack of passenger and cargo attraction, endangered health of passengers and train officers due to penetration of sands into the coupes through ventilation system, increased fracture-caused maneuver in the transmission equipment and wagons, and severe reduction in the eyesight in the region (3 km). Some of the adverse effects of desert areas on well-being and comfort of the train personnel and passengers include discomfort of the passengers due to the generation of low wavelengths as the result of the presence of sand on railways, which causes noise and vibration and, consequently, discomfort of the passengers, reduced speed, delay in train arrival, reduced efficiency of the human force and even machineries in desert climate, track obstruction, stop of passenger trains, creation of noise and sparks on railways resulting in the discomfort of passengers and officers, penetration of dust into the coupes as the consequence of sand storm, and bothering the passengers, especially those with heart and pulmonary diseases. The desert and dry landscape around the railway track can have adverse impacts on passengers and those train officers who constantly pass these critical routes. However, it may be considered as a part of the touristic and recreational attraction for passengers and tourists within the region [Ahmadi H,2003, Bagheri Azam, 2003].

Figure 1. Entry of sand into railway track, burial of track under sands, and inefficiency

3. Transfer of Sand Particles in Desert Areas

Wind can transfer the particles laid at the land surface. The transfer rate, displacement value, and deposition velocity directly depend on the wind power (speed) and particle diameter. Depending on the particles' weight, the particles are carried by wind in three ways: a) suspension movement of particles (very fine particles): the movement height of these particles is estimated to be nearly 2-4 m; b) saltation movement of particles (medium particles), the medium-sized particles (0.15-0.25 or 0.5 mm) are moved and, then, thrown onto the air as the result of collision of the sand particles with each other (called saltation movement), the height of which commonly reaches 2 m; and c) rotation-creep movement (coarse particles): the coarser particles (average diameter of above 0.5 mm) cannot be moved and thrown onto the air due to their high weight and coarseness, but when the wind reaches the sufficient speed, these particles start a forward movement by rotation or rolling, which is called rotation movement and occurs at the surface layers of the ground. Sand removal and sand deposition occur in the areas that are known as sand removal basin and sand deposition basin (sequestration) basin, respectively [Ansari R.2006].

Figure 2. Sand movement steps (removal and deposition basins) and various types of sand particles transfer in desert areas

4. Methodology of Analysis of the Sand Dunes Movement Through Canals Provided in Embankment and Humped Slab Track

In the present paper, initially, due to the necessity of high precision and accuracy, the primary modeling for the construction of a canal with circular cross-section with the diameter of 1.5 at different heights from railway surface was performed in Rhino software, which is engineering design software. Then, meshing of the model was performed in Gambit software; subsequently, after determining the specifications of the materials (sand, air, and concrete surface), selecting the analysis model, determining the number and type of flow phases (2-phase and 2&3-dimensional), and specifying the boundary conditions (sand entry velocity), the model was imported into Fluent software for analysis. All of the resulted diagrams, tables, and analyses were indeed the outputs of this engineering software.

5.Geometrical Form, Dimensions of Canal, Geometrical Forms of Hump Based on the Engineering Limitations and Requirements, and the Aerodynamic and Fluid Problems

Regarding the studies conducted on aerodynamic problems, air resistance, Bernoulli's principle, and relationship between speed and pressure as well as the previous studies on the current subject, it can be said that creating a canal through the sand pass route within the rail embankment can have a considerable effect on the sand pass rate so that, in the areas of the railway track where there is a space for sand transmission, sands will not be accumulated on the track and will pass it; consequently, there will be a traffic flow along the railway track. In the following sections, various types of forms as well as the relevant experimental and scientific results and their application will be investigated. The forms investigated in the present paper included: a) rectangular forms, b) square forms, and c) bent and semi-circle angles.

Accordingly, with regard to the above-mentioned conditions and options as well as their accordance with aerodynamic conditions, a humped form can follow the option (c), i.e. "bent or semi-circle angles", which was the basis of the primary design of the geometrical form of the modeled canal.

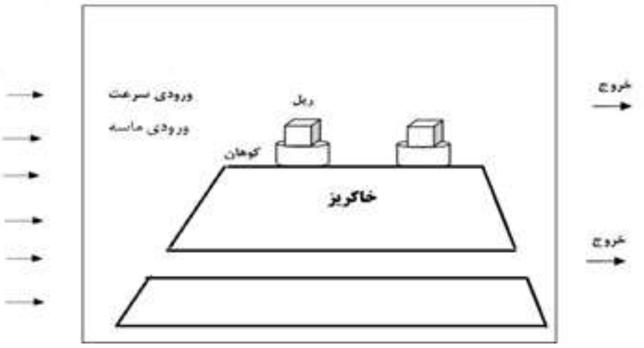


Figure 3. Determining boundary conditions of model

6. Slab Track, Hump and the Canal Chosen for Simulation Model

Based on the investigations conducted in the paper entitled "Investigation of Various Geometrical Forms of Hump on Sand Pass through Railway Track in Desert Areas", the geometrical form MC20 was selected as the optimal form for passing the sands. Similarly in the present paper, the same model was used with the following design [Fathi A.Zakeri J.A, 2015]. It must be noted that in all the models, the distance between the canal floor and ground surface was considered equal to 1 m.

Figure 4. Dumped slab track design

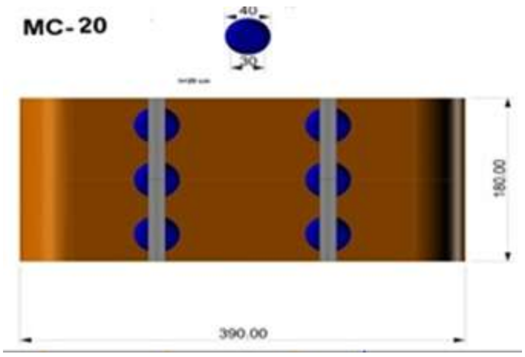


Figure 5. Dimensions and sizes of geometrical form of circular hump M-C with height of 20 m (hump model selected for investigating the four designs of canal)

Table 1. Geometrical form, dimensions, size, and installation location of canal (in accordance with (Fig.5)

No.	Canal model	Diameter (cm)	Geometrical dimensions and size (cm)
1	Without canal M1-WP	-	Embankment without canal
2	Circular canal M2-PO	150	Circular canal with distance of 1.5m and height of 0 from embankment surface
3	Circular canal M3-P1	150	Circular canal with distance of 1.5m and height of 1m from embankment surface
4	Circular canal M4-P2	150	Circular canal with distance of 1.5m and height of 2m from embankment surface

Table-2. Geometrical form of hump along with geometrical dimensions and size

No.	Hump model	Height (cm)	Geometrical dimensions and size
5	Perfect circular design ($M\text{-}C_{20}$)	20	Diameter of floor (lower) and upper circles (under the rail) equal to 40 and 30 cm, respectively, and height of 20 cm
6	Perfect circular design ($M\text{-}C_{20}$)	25	Diameter of floor (lower) and upper circles equal to 40 and 30 cm, respectively, and height of 25 cm
7	Minimized compound design (rectangle-semicircle) ($M\text{-}_{TMI20}$)	20	Floor: rectangle with length of 40 cm and semicircle with radius of 12.5 cm; Upper: rectangle with length of 30 cm and semicircle with radius of 8 cm

7. Measurement Method of Behavior of Flow on the Surfaces [Computational Fluid Dynamics (CFD)]

The methods including testing in wind tunnel, installing thin strands on surface, and PIV laser method are very complicated, and are gradually being replaced by computational fluid dynamics (CFD) methods. In this method, the model is constructed using a computer as well as thousands of complex mathematical equations. The computerized methods also model the air flow and facilitate its examination. In the present research, the CFD method was used as well [Sanieinezhad, 2010, Dehghani Sanij, 2014].

8. Analysis of Canals Provided at Various Heights by Fluent Finite-Element Software (Numerical Method-CFD Method)

Being constructed and meshed in Gambit software, the model was imported into Fluent software. After ensuring the accuracy of transmission of the geometrical model, the under-analysis problem was examined and solved in both 2D and 3D modes. Generally, various fluid problems can be categorized in two major groups: unsteady (time-variant) and steady (time-invariant) [Jadid, 2012]. Accordingly, the studied problem is a time-variant or unsteady one; thus, it was solved using a time-variant or, in other words, unsteady solver. In this problem, the Eulerian model with two working phases was selected; then, the selected model was solved in terms of the turbulence of the problem using standard k-epsilon model, the data of which are presented in Table (5). The model constructed for simulating the sand dunes' movement was very complicated and time-consuming due to having two phases, requiring high precision for following the sand particles with small dimensions, and finally its 3-dimensions. Therefore, a period of about 120 h (5 days) was spent on solving the 3D model of this problem due to its special conditions as well as high number of the meshes used in the investigated geometry (nearly 800000 meshes per model).

Table 3. Conditions of problem solution in Fluent software

Solver	Pressure-based
Space	2D and 3D
Time	Transient-unsteady
Velocity formulation	Absolute
Unsteady formulation	1^{st}-order implicit

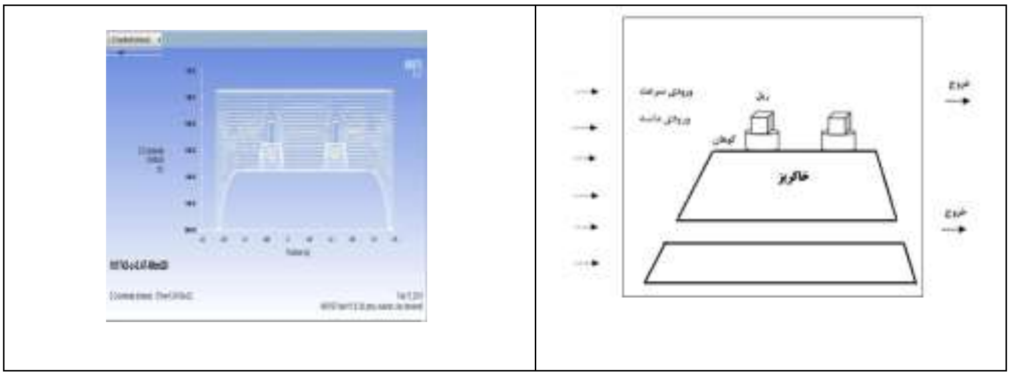


Figure 6. Boundary conditions of model (left image) and schematic image of primary model for importing into Fluent software (right image)

Table 4. Defining boundary conditions in analysis by Fluent software

Parameters	Value	Parameters	Value
Sand density	2500 kg/m^3	Compression coefficient	1 (uniform particles)
Sand viscosity	0.001003 kg/m/s	Sand entry velocity	10 m/s
Average diameter of sand particles	0.0005 m	Time step	10^{-5} s

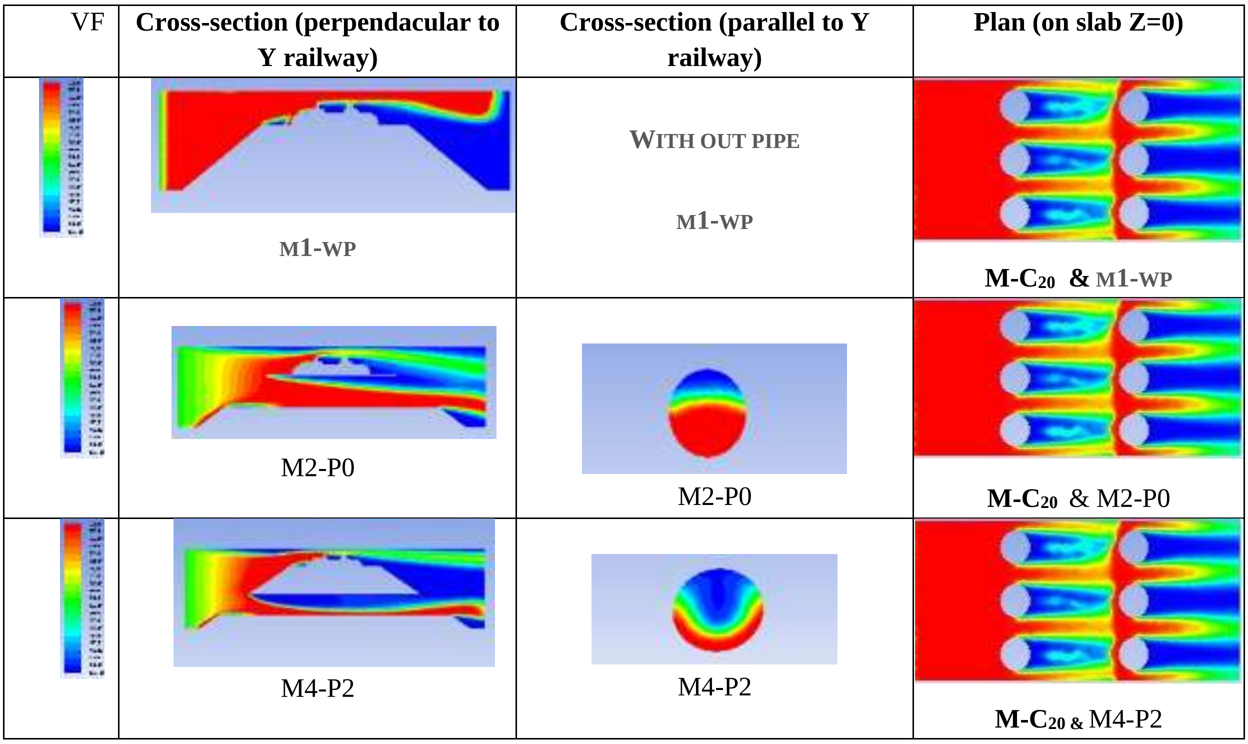


Figure 7. Schematic comparison of volume fraction (VF) of three types of canals M1, M2, and M4 with hump model M-C$_{20}$

As can be seen in Figure (8), for the VF value (ratio of volume fraction of sand to fluid volume) in model M4-P2, there was less sand within the canal (cross-section X), while at cross-section Y, the form M4-P2 had good conditions. This indicates that this model was more successful in transferring the sands. Indeed, this was a merely superficial examination; thus, a more precise analysis requires the investigation of the numbers, tables, and diagrams, which will be presented later.

9. Analysis of Sand Transfer Status in Different Models

With regard to the analysis performed in Fluent software, Table (5) is presented as the output of the geometrical calculations and the software.

Description of the variables in Table (5)

TIME indicates the time of modeling in Fluent software, MAS is the mass of accumulated sands on humped slab track in kg, and VF is the ratio of sand volume fraction to fluid volume, which can be measured in three maximum, minimum, and average modes.

Table 5. General specifications of the model's output – quadruplet forms

Model/criteria	TIME	VF-m	VF-max	MAS (kg)	MAS (Integ)
M1-WP	1.107	0.395	0.63	56484	33,546
M2-PO	1.29	0.3255	0.63	59130	27,056
M3-P1	1.31	0.304	0.63	78955	37,135
M4-P2	1.452	0.286	0.63	99482	47,219

Diagram 1. Comparing average VF of three canal designs M1, M2, M3, and M4 with humped model M-C20

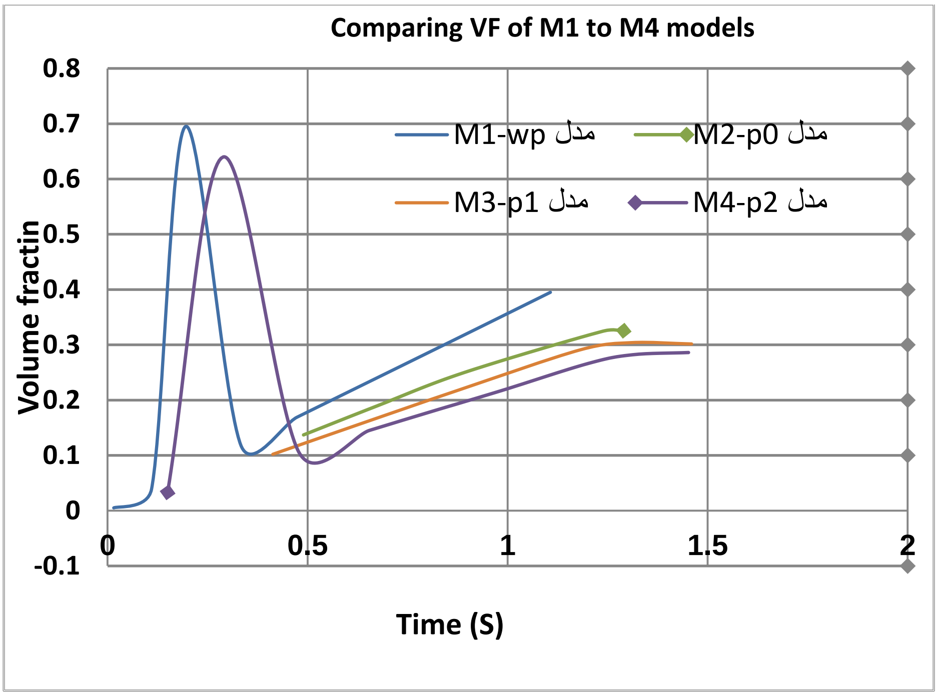
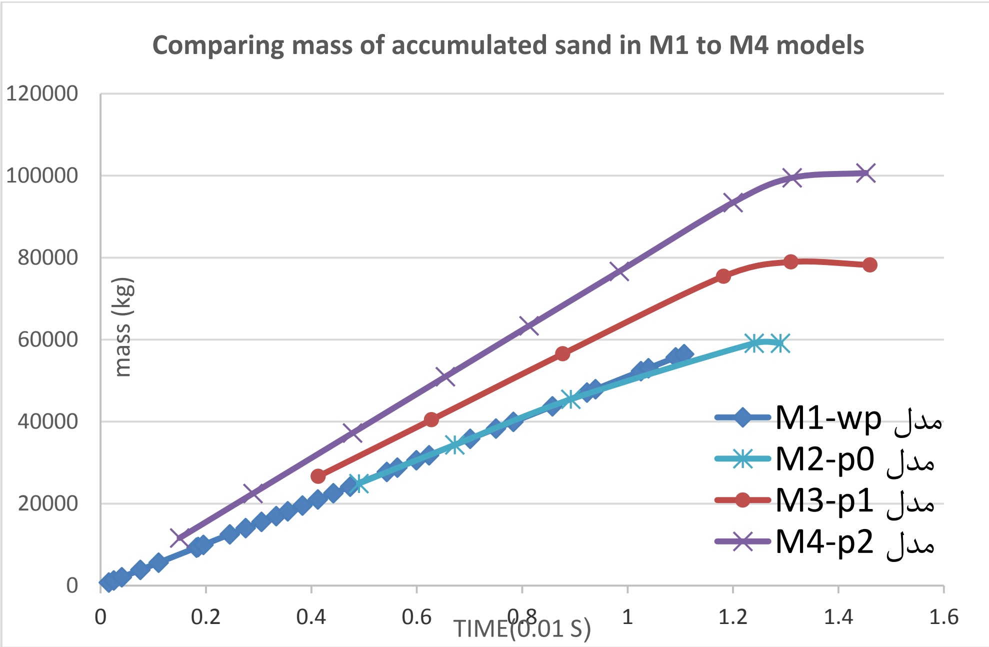


Diagram 2. Comparing accumulated mass in three canal designs M1, M2, M3, and M4 with humped model M-C20



As shown in Diagram (2), by increasing the time, the sand accumulation rate in the models was increased with the increase in the model volume from M1 to M4, which is natural.

A): **Analysis of the results in Table (5)**

- Analysis of VF values

Regarding the values obtained for VF (volume fraction), the VF value in model M4-P2 was less than that in other models, which indicated that this model was more successful than others. In other words, the sand subsidence rate in this model was less than others so that the major part of the sand passed (Diagram-1).

- Analysis of MASS, and MAS INTEGRAL values (Diagra-2)

Regarding the increased volume of the model from models 1 to 4, the increase in MASS value was natural and could not be used as a comparative value.

In Diagram (1), one of the most important extractable points was the convergence of all the models in 12,000 sec, which indicated proper modeling. As a result, Figure (8) and Diagram (1) show that the VF value in M4-P2 design was less than that of others.

Table 6. Specifications of the model output – quadruplet forms (pipe cross-section)

Model/criteria	Mass flow rate (kg/s)	M.W.A	A.W.A
M1-WP	0	0	0
M2-PO	249.66	0.565	0.455
M3-P1	583.7	0.525	0.365
M4-P2	2363.31	0.45	0.3186

B): **Analysis of the results in Table (6)**

In this section, a circular cross-section was passed perpendicular to the model, perpendicular to the pipe, and through the two rails; thereby the following parameters were measured:

- Analysis of MASS FLOW RATE (kg/s) (sand flow rate from selected surface)

The amount of the sands passed through the given cross-section was measured. According to Table (2), the highest rate was related to model 4 (M4-P2), which indicated that it passed the highest amount of sand.

- Analysis of M.W.A (Mass Weighted Average), average weight on surface, and A.W.A (Area Weighted Average)

The lowest values of these parameters were related to model M4-P2, which indicated the minimum amount of sand at the selected surface; thus, model M4 had the best performance in this analysis as well.

According to the diagrams and tables, model M1-WP had the minimum efficiency in this simulation and, thus, not recommended.

In this analysis, due to the difference of the model volumes in the simulated instances, the most important parameter to be compared was VF related to the total model volume, the reduction of which would lead to the model's optimality. Therefore, according to the comparisons made in this regard, model M4-P2 was introduced as the best choice since it passed the maximum amount of sand. Other measured parameters were used for control, additional precision, and validation of the model.

10. Summary and Conclusion

The approach followed in the present research was to leave open the sand flow route. This study was aimed to investigate the solutions for reducing the crisis in sand-absorbing railway tracks as well as the solutions for reducing the sand accumulation on railway tracks (including construction of sand pass canal in embankments and modification of geometrical form of humped slab tracks) and to present an optimal design for the provided canals in order to facilitate the sand movement. For this purpose, different distances of the canals from the railway surface (0-2 m) and the humped geometrical form, which had appropriate aerodynamic behaviors, were designed and simulated. Due to the optimality of the circular cross-sections in aerodynamic problems, the circular form with the diameter of 1.5 m was considered for the canals. These canals were located on the embankment at different distances from the surface. The designs were simulated in Fluent software. Based on the results of the analyses performed on the canals, the M4-P2 design (with the distance of 2 m from the embankment surface and a hump with the conic-circular form and height of 20 cm (M-C20)) was the optimal design. Furthermore, it was shown that the circular cross-sections could pass the sand better than the other studied forms.

Finally, considering the sand pass time, sand deposition volume, canal filling time, slab surface area, and track obstruction, the M4-P2 design with M-C20 hump model can be proposed as the optimal option. Indeed, the selected design must undergo the final test using the experimental sample construction method in sand-absorbing tracks in order to take steps toward the development of such railway tracks.

11. References

-Ahmadi H. (2003) “Investigating wind corrosion control methods for railways protection (Case study: Bafgh Region), Technical Note, Shahid Chamran University of Ahvaz

-Ansari, R. (2006) “Newest methods for gravel fixation”, South-eastern Railways Organization; Conference on Railway Problems in Desert Regions

-Bagheri, Azam (2003) “Review of climate and transportation focusing on temperature and wind in Kerman-Zahedan railway track area; Collection of articles on railway problems in desert regions”, Islamic Republic of Iran Railways.

-Dehghani Sanij, M. (2014) “Numerical simulation in Fluent software”, Tehran: Naghoos Publications

-Etihad Rail (2009) "Geomorphologic study and computer modelling of sand dunes", Ethhad Railway Company

-Fathi, A. and Zakeri, J. A. (2015) “Investigating effects of various geometrical forms of hump on sand flow through railway tracks in desert regions”, Quarterly Journal of Transportation Engineering; Ministry of Roads and Urban Development, Vol. 1, No.2, pp.104-187.

-Fathali, M. (2008) “Pavement of humped slab track for resolving railway track problems in desert regions”; MSc. thesis in railway engineering; Iran University of Science and Technology.

-Forghani, M. (2006) “Investigating railway problems in desert regions”; MSc thesis in railway engineering; Islamic Azad University, (Science and Technology Branch)

-Hasani, M. (2011) “Railway tracks and sand dunes fixation technologies”, Technical Structures and Tracks Supervision Group of Southeastern Railways Organization, p.35

-Hasani, E. (2012) “Report on railway problems in desert regions”, Transportation Research Center, pp. 44-48

-International Desert Research Center. University of Tehran (2012) “Sand dunes inhibitor non-oil liquid (polymeric non-oil mulch)”, Research Report.

-Jadid, M. (2012) “Boundary conditions and turbulence parameters in Fluent software”, Department of Computational Fluid Dynamics, Isfahan University of Technology, Technical Note.

-Jahangirian, A. (2008) “Investigating effects of retaining walls on sand storms using numerical solution of flow”, Research Center of Islamic Republic of Iran Railways

-Railways Infrastructural Supervision and Engineering Office (2005) “Collection of articles on railway problems in desert regions, Islamic Republic of Iran Railways

-Sanieinezhad, M. (2010) “An introduction to simulation and modeling of turbulent flows”, Sharif University of Technology Press

-Zakeri J. A., Esmaeili, M. and Fathali, M. (2011) "Evaluation of humped slab track performance in desert railways", Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Volume 225, Issue 6, pp. 567 - 574.

-Zakeri J. A. and Abbasi, R. (2012) "Field investigation of variation of loading pattern of concrete sleeper due to ballast sandy contamination in sandy desert areas", Journal of Mechanical Science and Technology, Vol. 26, No. 12, pp. 3885~3892

-Zakeri, J. A. (2012) "Investigation on railway track maintenance in sandy-dry areas", Structure and Infrastructure Engineering, Volume 8, Issue 2, February, pp. 135-140.

-Zakeri, J. A. (2005) "Special sleeper design for reducing railway track maintenance costs", Research Report No. 10341, Iran University of Science and Technology.

-Zakeri J. A. (2007) "Requirements of railway route design in desert areas", Proceedings of 8th International Conference on Railway Engineering, London.

-Zakeri, J. A. (2012) “Introduction to modern pavement – humped slab track – for resolving railway track problems in desert regions”, Modares Civil Engineering Journal, Vol. 10, No.2, pp.7-14

http://www.tubulartrack.co.za/index.php/2014/01/third-balloon-oheavy-haul-coal-line-ermelo