Work 41 (2012) 3367-3371
DOI: 10.3233/WOR-2012-0609-3367
IOS Press

Review of walking hazards for railroad workers

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Abstract. This is a review of walking tasks in the railroad environment, and the injuries that result from slips, trips, falls, or other acute or even non-traumatic exposures. The lack of federal regulations for railroad walkways has led several states to develop and enforce their own regulations. Support from the research literature for such regulations has come from biomechanical studies of the effects of walking on railroad ballast, which will be reviewed.

Keywords: Railroads, ballast, falls, biomechanics, balance

1. Introduction

The railroad environment has some unique walking conditions, including the rock aggregate (ballast) used to support the track structures while providing drainage. Many railroad workers have duties that require them to walk on these ballast surfaces, and yet the Federal Railroad Administration (FRA) in the U.S does not regulate walkways. This is a review of: 1) the railroad jobs that involve walking, particularly on ballast, 2) the statistics concerning injuries of railroad workers that relate to interactions with walking surfaces, 3) the ballast specifications used by the railroads and regulations involving walking surfaces at the railroads, and 4) the research on the biomechanical and physiological effects of walking on ballast. This review will synthesize these topics to promote the provision of adequate walkways for railroad workers.

2. Railroad Jobs That Involve Walking On Ballast

Railroad jobs involve walking inside railroad equipment repair and maintenance facilities (usually on concrete floors), walking in railroad yards, and walking along the tracks outside the yards. While[*] standing and walking on concrete floors may be a concern for fatigue or long term effects, working inside railroad facilities typically does not require exposure to walking on uneven surfaces; however, trip hazards still exist. Working in railroad yards and along the tracks usually exposes the workers to walking on ballast and uneven surfaces. Employees in the shops include electricians, machinists, pipefitters, mechanics, and some carmen. Employees working in railroad yards are car inspectors, some carmen, switchmen, hostlers, yard brakemen, yard conductors, and yard maintenance crews including signalmen, trackmen, and welders. Outside the railroad yards conductors, trackmen, welders, signalmen, and bridge workers all walk along and work on the ballast supporting the tracks.

Trainmen (switchmen, brakemen, and conductors) have job duties such as inspecting train brake systems and coupling air hoses that can require them to walk the entire length of a train on ballast. They also have to walk ahead and behind trains to throw switches; some companies still allow trainmen to get on and off moving equipment, although most Class I railroads have prohibited this practice for safety reasons. Dismounting a moving train onto an uneven ballast

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surface is an obvious concern – in fact the Medical and Surgical Section of the Association of American Railroads (AAR) in 1948 documented injuries to the semilunar cartilages of the knee in trainmen who dismounted moving trains or were involved in switching operations [13].

In general, the yard environment can be more controlled than the conditions out along the main lines. Larger gradation ballast is needed to support the track structures and to provide drainage. Often the tracks have to be built up to approach bridges, accommodate curves, or tracks are built up over time to remedy poor drainage situations. The result can be steep slopes of large ballast up to the tracks. In railroad yards, however, the terrain is typically more flat and the tracks are not built up as much, so the slopes of ballast up to the tracks are less steep. Also, drainage systems can be installed beneath the tracks so that large ballast is not as essential for that purpose. Therefore, smaller ballast can be used and walkways can be established.

3. Injury Statistics for Railroad Workers Exposed to Walking

The FRA collects injury data from U.S. railroads. In calendar year 2011 at least 15.6% of all injuries were related to walking, slipping, stumbling, and falling due to debris (objects on the walking surface including ballast or spikes, etc.), climatic conditions, or irregular surfaces. These recent data are consistent with prior experience: in 2003 15.9% of all injuries were attributed to walking and accounted for 18.6% of days lost from work [7].

Trainmen (conductors, switchmen, and brakemen) who make up trains in yards, inspect cars in yards and along the main line, and set out or pick up cars at industrial sites experience 28% of all reportable injuries and 42% of lost workdays, even though they make up less than 10% of the workforce. Walking in railroad yards accounted for over 15% of all lost day injuries in yard trainmen from 1979-1986 [5].

An FRA study in 2001 [8] investigated yard accidents and injuries, and found strains and sprains the most prevalent injuries: 58% of lost workday injuries, and 63% of lost workdays. The torso was the most affected body region (42% of injuries), followed by the lower extremities (29% of injuries). They found that slips, trips, and falls were the triggering event for the largest number of injuries (42%). The act of walking, running, or stepping over accounted for the most injuries (25%), and the greatest number of lost workdays.

4. Ballast Specifications and Walkway Regulations

Railroads began to use ballast to support track structures at the outset, but with heavier wheel loads, higher operating speeds, and greater train lengths, the performance of the track system needed improvement. Organizations such as the American Railway Engineering and Maintenance-of-Way Association (AREMA) conducted testing of track systems, including ballast, to develop specifications for track construction. They specified types of rock, cross-sections for track structures, and ballast gradation [2]. Railroad ballast is specified by gradation, a process that requires a certain percentage of the aggregate to fit through a sieve of squares of particular dimensions. For main line applications, the maximum square opening is 75 mm (3 inches), with at least 90% of the aggregate passing through a 63 mm (2.5 inch) opening. For yard walkway applications, the maximum size of the aggregate passes through a 37.5 mm (1.5 inch) opening, but at least 90% of the aggregate must pass through a 25 mm (1 inch) opening. Walkway ballast is specified much smaller than main line ballast. There are also specifications for the amount of slope for walkways beside tracks (no more than 1 inch rise in 8 inches).

California has regulated the construction, reconstruction, and maintenance of walkways for railroad employees since 1963 [3]. All railroads operating in California must provide reasonably safe and adequate walkways adjacent to tracks in switching areas, and keep them free from vegetation. These requirements apply to switching areas along main, branch, and industrial trackage.

Washington State mandates that walkways must be provided in yards where employees regularly work on the ground (WAC 480-60-035) [9]. The size of the ballast is regulated, consistent with the walkway ballast described above. Ease and safety of walking are the primary considerations for providing walkways. Walkways must have a reasonably smooth surface and must be maintained in a safe condition. This includes removal of debris and irregularities like depressions in the ballast.

5. Effects of Walking on Ballast

An experiment [1] investigated biomechanical differences in walking on level concrete versus walking on walking ballast (WB) or main line ballast (MB) at a transverse angle of 7 degrees. Results confirmed previous unpublished findings: walking on MB caused significantly greater rearfoot motion and greater variability in that motion when compared to either walking on (WB) or on level concrete. Results revealed on average a 58% increase in motion of the rearfoot, a 21% increase in the rate of rearfoot motion, and a 66% increase in the variability in rearfoot motion when walking on MB versus WB. There were no significant differences in rearfoot motion between WB and level concrete. The implications of these findings is clear - if WB were placed in the locations where railroad employees have to walk, stresses in their lower extremities would be lowered to a level consistent with walking on level concrete. However, requiring railroad employees to walk on MB dramatically increases the biomechanical stresses in the lower extremities. These results led to the conclusion that there were increased stresses applied to the lower extremities of railroad employees when they were required to walk on MB. Compounding the problem, repeated dismounting from equipment mounted on the rails onto ballast creates axial (compressive) loading of the articular cartilages.

After the first study, a more detailed experiment was proposed to investigate the three-dimensional torques and forces and the muscle activation patterns of the lower extremities when walking on ballast. The proposal was sent to all of the Class I railroads, the AAR (the trade organization for U.S. railroads), and the FRA. Only one railroad responded, but claimed it was already involved in a comprehensive study of the topic. The FRA agreed to provide funding for our study in 2006. The first publication resulting from the project is now available [12].

Before the study could be accomplished, a determination was needed to see if ground reaction force data could be acquired successfully from a ballast walking surface. Wade and Redfern [11] found that the ground reaction forces walking on ballast versus a flat hard surface do not differ significantly. Given these results, the larger experiment was performed [12]. Twenty healthy adult men walked along 3 distinct pathways [No Ballast (NB), Walking Ballast (WB), and Mainline Ballast (MB)]. Full body motion, ground reaction forces, and EMG signals from the lower extremity were collected. Three-dimensional joint moments were calculated at the hip, knee, and ankle during repeated steps on the walking surfaces. Parameters derived included moment trajectories, moment ranges, EMG activity, spatial EMG measures, and temporal gait measures. The moments tended to be reduced on ballast for the hip and knee, except for more varus moment in the NB condition for the knee versus valgus moment for the ballast conditions. There were greater ankle eversion moments on MB and WB compared to NB. For the hip and knee, the moment ranges for the ballast conditions had lower ranges of moment in all planes compared to the NB condition. Only ankle inversion/eversion ranges differed, with the range being greater for the ballast conditions than the NB condition. While joint moments generally decreased on ballast, the EMGs increased for MB and WB compared to NB. EMG means and peaks were greatest for MB and least for NB, while burst durations increased progressively from NB to WB to MB. Co-contraction was seen in the three antagonistic muscle pairs evaluated, increasing progressively from NB to WB to MB. These changes were seen despite temporal gait changes such as decreased speed on MB versus WB or NB conditions, and increased stance and swing duration and double and single support duration for MB and WB compared to NB. Based on these findings, it appeared that walking on railroad ballast increased muscle activation to control the moments at the joints of the lower extremity, potentially increasing both localized fatigue and the compressive loading on those joints.

A ballast study funded by Union Pacific was completed and approved as a dissertation in July 2008 [6]. The stated purpose of the study was: "to develop a technique capable of performing an analysis of lower limb biomechanics for walking on irregular surfaces, specifically crushed rock aggregate (ballast) to better understand lower extremity biomechanics. The relationship between mechanical loads and subsequent development of knee OA is unclear. A goal was to better understand mechanical loading during ambulation on aggregate surfaces, specifically of the knee, to quantify exposures to be used in epidemiological studies to help identify causation." The dissertation had 4 parts: 1) validation of a 3D motion capture and ground reaction force system for accurate and reliable measures of center of pressure and force on aggregate surfaces, 2) gait analysis on sloped ballast surfaces – temporal-spatial parameters, 3) kinematics parameters ambulating on ballast, and 4) an investigation of lower limb kinetics and human locomotion on ballast. Ten male railroad workers walked on trays filled with ballast or on a plywood surface atop the tray. For the first experiment (temporal-spatial gait parameters), only 5 trials were run for each condition, but instead of averaging the data the investigator hand-picked a "representative" trial from each condition to analyze, based on a subjective judgment of that trial best representing the majority of the other trials for that group. He found decreased velocity on the ballast versus the no ballast surface, along with decreased cadence. Velocity decreased when the surface was sloped (apparently at 7 degrees), and there were some differences between the up-slope foot and down-slope foot parameters. He concluded that: "skilled railroad employees who have experience walking on aggregate surfaces reduce their walking speed and cadence when ambulating on crushed rock ballast." For the kinematic results once again a trial was handpicked instead of averaging the trials. The overall kinematic finding was that walking on ballast slightly altered the kinematics of certain sagittal plane parameters, but sometimes WB parameters were more different from NB than MB and sometimes MB parameters were more different from NB than WB. The kinetic analyses on the same data again used only "representative" handpicked trials. Ballast type had significant effects for some kinetic variables, but not for others. Slope had the greatest impact on these differences. He concluded that: "Increased knee adductor moment from walking on slanted surfaces may contribute to an increase in load of the medial compartment of the meniscus which has been associated with the progression of knee OA." He also concluded that walking on WB appeared to be more closely related to walking on a hard smooth surface than MB. Unfortunately, handpicking trials for analysis is not a practice that typically satisfies peer review – no peer-reviewed publications have resulted from this study to date.

Another graduate student took Merryweather's data and used it for his Master's Thesis [14]. He found that "walking on large and small ballast significantly increased heel and toe clearance compared to walking on a hard, flat surface. After walking on large and/or small ballast for a long time, fatigue may affect a person's lower extremities so that heel/toe clearance is not met. This could ultimately lead to catching ballast with the heel or toe and the initiation of a trip or induced fall. It is recommended that employers provide a working environment to: 1) control working time on larger ballast, 2) train workers about the importance of being aware of the walking surface and the potential increase in trip/fall likelihood when fatigued, 3) provide periodic rest breaks to minimize fatigue and provide opportunity for rest and recovery." This study had the same limitations as Merryweather's since it used his data and again focused on selected trials only. He concluded that: "…walking on large ballast presented an increased chance for the subjects' footwear to strike or "catch" obstacles. In other words, large ballast might present a greater potential of a trip/fall hazard."

Another study on rearfoot motion (RFM) was supported by BNSF [4], with a stated purpose: "… to partially replicate and supplement the study conducted by Andres et al. (2005) to further investigate the effects of the sloped and ballasted (yard and mainline) walking surface condition on RFM and other select gait variables." This study had 15 male and 5 female subjects and had a total of six surface-slope conditions (surfaces were equivalent to NB, WB, and MB; slopes were 0, 5, and 10 degrees). This study also used trays of ballast – raked between trials. It was unclear how many trials were completed, so the statistics cannot be evaluated. Despite this and other shortcomings, they reported that subjects decreased their walking velocity, step length, and step rate as conditions changed from solid and flat to sloped and ballasted, reflecting a progressively more cautious gait as the walking surface changed from flat and solid to sloped and ballasted. The RFM parameters also increased with ballast and slope compared with a flat and solid surface. A major thrust of the study was to assert that walking on ballast does not increase the risk of injury, although none of the data collected or reported have anything to do with injury risk. This study is unpublished, and the only possible conclusion to draw from the study – if the statistics and methodological problems could actually be ignored – is that RFM variables during the early stance phase of gait increase when walking on ballast, even when the gait becomes "more cautious."

Neither the UP study nor the BNSF study refutes the findings of Andres et al. [1]. Both studies have fatal flaws that would preclude them from being published in a peer-reviewed refereed journal. Most importantly, neither study provides any explanation for the kinematic and kinetic effects of walking on ballast in stark contrast to the study [12] that elucidated the neuromotor control strategy of increasing co-contraction to stiffen and stabilize lower extremity joints when walking on ballast.

A more recent study [10] exposed subjects to prolonged walking on ballast and assessed changes in postural control due to this exposure, compared to walking on a surface without ballast. Participants were tested with six NeuroCom® Equitest postural stability testing conditions prior to exposure and then every 30 minutes during a 4 hour session. Walking on ballast for extended durations had a deleterious effect on postural stability compared to walking on a surface without ballast. These effects may increase the likelihood of falling if a slip or stumble occurs on the uneven ballast surface.

In summary, walking conditions for railroad workers who must walk to do their jobs have an impact on both the joint stresses in their lower extremities and their postural control. Walking on ballast affects the neuromuscular responses, apparently to stiffen the lower extremity joints, which in turn may affect the postural control mechanisms in a manner that increases the risk of slips, trips, and falls. The use of WB where railroad workers have to walk would minimize these effects, and should be pursued aggressively.

References

[1] R.O. Andres, K.G. Holt, and M. Kubo, Impact of railroad ballast type on frontal plane ankle kinematics during walking, Applied Ergonomics (2005), pp. 529-534.

[2] AREMA Manual for Railway Engineering, Part 2 – Ballast, American Railway Engineering and Maintenance-of-Way Association, 1999, pp. 1-2-1 to 1-2-25.

[3] General Order No. 118, Public Utilities Commission of the State of California, Regulations governing the construction, reconstruction, and maintenance of walkways adjacent to railroad trackage and the control of vegetation adjacent thereto, effective April 29, 1963.

[4] L. Hutcheson, J. Casebolt, J-H Ryu, and Y-H Kwon, The effects of typical railroad ballast surface and slope conditions on rearfoot motion in walking, unpublished report, 2009.

[5] S.R. Kuciemba, G.B. Page, and C.J. Kerk, An ergonomic investigation of railroad yard worker tasks, in: Trends in Ergonomics/Human Factors V, F. Aghazadeh, ed., Elsevier Science Publishers, Holland, 1988, pp. 1061-1068.

[6] A. Merryweather, Lower limb biomechanics of walking on slanted and level railroad ballast, Ph.D. Dissertation, University of Utah, 2008.

[7] Railroad Safety Statistics, Final Report 2001, U.S. Dept. of Transportation, Federal Railroad Administration, July 2003.

[8] S. Reinach and J. Gertler, An Examination of Railroad Yard Worker Safety, U.S. Dept. of Transportation, Federal Railroad Administration, DOT/FRA/ORD-01-20, July 2001.

[9] WAC 480-60-035, Walkways, Washington State Legislature, effective 2/21/00.

[10] C. Wade, J.C. Garner, M.S. Redfern, R.O. Andres, and J. Roche, Impact of extended durations to ballast and postural stability, in: Proceedings of the Human Factors and Ergonomics Society 55th Annual Conference, September 2011.

[11] C. Wade, and M.S. Redfern, Ground reaction forces during human locomotion on railroad ballast, J. of Applied Biomechanics (2007), pp. 322-329.

[12] C. Wade, M.S. Redfern, R.O. Andres, and S. Breloff, Joint kinetics and muscle activity while walking on ballast, Human Factors 52(2010), pp. 560-573.

[13] J.H. Wagner, Injury to the semilunar cartilage of the knee, in: Proceedings of the Twenty-Eighth Annual Meeting of the Association of American Railroads, Medical and Surgical Section, Chicago, IL, June 21, 1948.

[14] B. Yoo, Trip/fall potential of walking on railroad ballast, Master's thesis, University of Utah, 2009.