Improvement/reinforcement of a ballasted track

Amélioration/renforcement d'une voie en ballast

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ABSTRACT: The paper deals with the reconstructions that were undertaken to correct multiple ballasted track formation failures for a heavy gantry crane. Finally, in 1988 a satisfactory design was obtained that incorporated geosynthetics.

RÉSUMÉ: L'article traite des reconstructions qui fûrent entreprises pour corriger plusieurs ruptures d'une voie ballast supportant une lourde grue à portique. Finallement, en 1988, une conception satisfaisante fût obtenue qui incorporait des géosynthétiques.

INTRODUCTION

A ballasted track to support a heavy lumber yard gantry crane (Figure 1) was placed in service in January 1986. The yard is in Northern Alberta, Canada with an average annual temperature of 1.25 °C and an average and maximum freezing index of 1,706 °C-days and of 2,631 °C-days respectively.

INITIAL 1985 CONSTRUCTION

Figure 2 shows a plan of the tracks layout and longitudinal sections. Figure 3 shows a typical at grade cross sections for the 1985 build. The 1985 subdrains, placed at the North end only, were of the aggregate geotextile-wrapped type without pipes. The track subgrade drainage was 2% across the full track width.

At the North end the original soil at subgrade elevation was both compacted and uncompacted fill. The surficial clays of the area are all lacustrine and were used as required. Their properties were liquid limit = 45 to 57, plastic limit = 19 to 25 (i.e., CL-CH soil), 100% washed through a 75 μm sieve, while an hydrometer test gave 93% passing at the 75 μm size; 91% at 50 μm; 83% at 20 μm; 74% at 10 μm; 65% at 5 μm; 54% at 2 μm; 44% at 1 μm. The proctor optimum moisture content (ASTM D-698) was slightly below the clay's plastic limit (w_{opt} = 17 to 22 %).

Pit run gravel compacted in 0.15 m layers to a total depth of 0.45 m acted as the sub-ballast. A poorly crushed large gravel 0.15 m depth below the base of the ties and extended 0.3 m beyond the ties at the top elevation of the ties was used for ballast. This material had about 55 % of particles with one crushed face was graded to an ASTM D-448 No. 4 grading. The track was consisted of jointed 88 kg/m crane rail, custom made steel tie plates, cut spikes, centrally position of 1.82 m long, 0.23 m wide, 0.175 m deep pressure creosoted Douglas fir ties right angles to the rail at 0.5 m centre to centre. The two independent tracks had a gauge of 60 m.

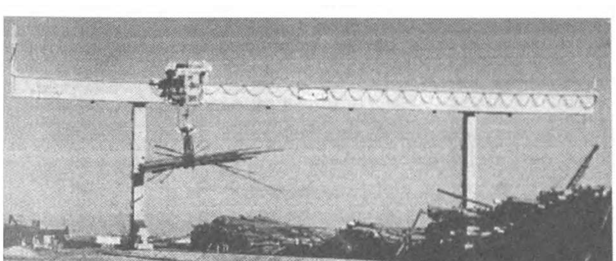

Figure 1. Gantry crane.

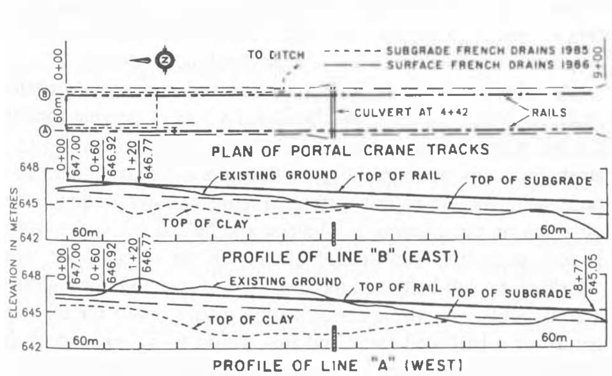

Figure 2. Track layout and longitudinal sections.

CRANE OPERATION IN 1986.

The crane started stockpiling logs on January 8. No track problems were noted until May 7 when excessive vertical and lateral differential deformations became suddenly evident. Deterioration first occurred along the more exposed west rail, but was followed a week later by similar problems to the east rail. In mid-May the track was re-ballasted to correct alignment and elevation. Operations were re-started May 18 and the same problems were again experienced. By June 27 failure of a number of the ties had occurred and the track was shut down.

Survey observations conducted on July 8 are shown in Figure 4 and record settlements up to a maximum of 0.23 m that had

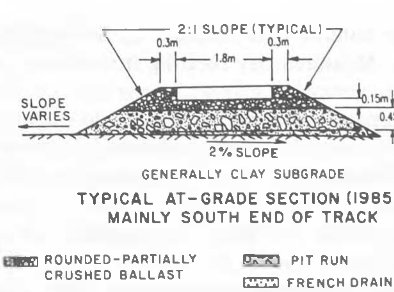

Figure 3. Cross sections of 1985 track construction.

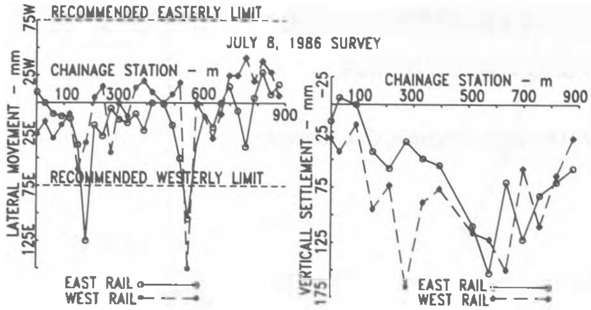

Figure 4. July 8th, 1986 measured track deformations.

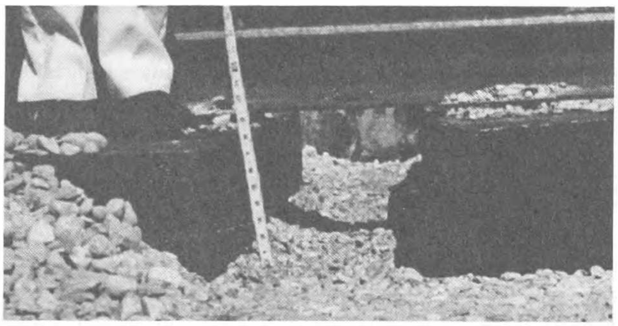

Figure 5. Example of 25 mm ballast above sub-ballast.

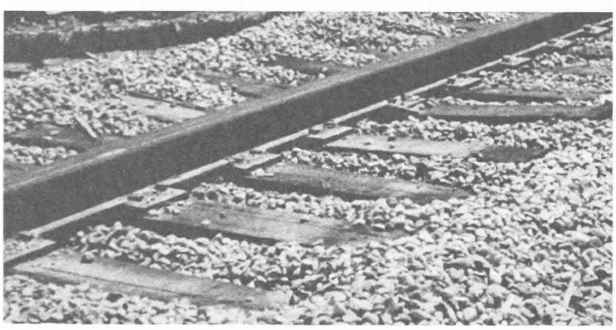

Figure 6. Ties split on tie centre line below rail.

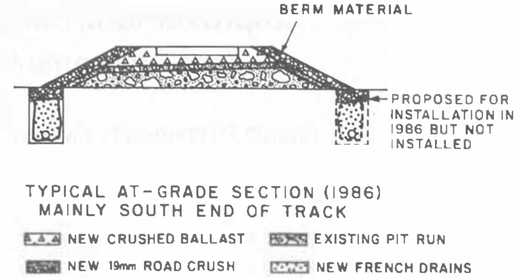

Figure 7. Cross sections of 1986 track rebuild.

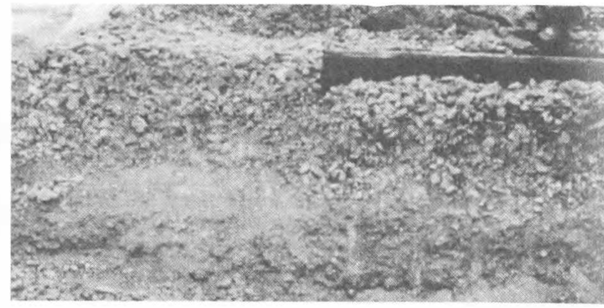

Figure 8. Ballast filled sub-ballast deformation.

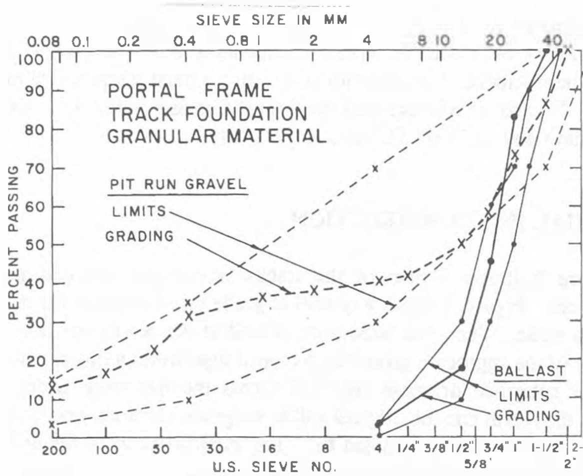

Figure 9. Original ballast/sub-ballast gradings and limits.

occurred since the re-ballasting of May 15 to 17. The conditions of the track are illustrated by (a) Figure 5 that shows a tie that has penetrated the ballast to within 25 mm of the sub-ballast surface, and (b) Figure 6 that shows a cluster of tilting ties with some split in the rail seat area (generally the ties dipped towards the west). In these locations the ballast had been pushed laterally, both into the cribs and beyond the tie ends. Numerous bent rails and eight broken joint bars were also noted.

SUMMER 1986 INVESTIGATIONS AND REBUILD

In the summer 1986 the original designer made investigations and stated/recommendations given below that resulted in a rebuild of the tracks, illustrated by the at grade cross-section shown in Figure 7:

No subgrade failures were detected by borings through the existing track. Measured clay shearing strengths, c_u, were over 200 kPa.

Poor performance of the ballast was due to the ballast's low crushed surface area. Importation of quarried granite rock (at FOB Can.$ 50.00 per ton) was recommended as replacement ballast.

The original design was based on maximum wheel loads of 285 kN (unspecified as static or dynamic). New calculations suggested use of a design value of 400 kN. This resulted two recommendations: (a) the track be stripped to the sub-ballast elevation and a 0.15 m of crushed road gravel (maximum particle size of 19 mm) be added followed by new quarried rock ballast (0.15 m thickness below the ties) to the top of the cribs, and (b) the tie spacing be reduced to 0.45 m centre to centre.

Drainage be placed along the outer full side of each track.

SPRING 1987 FAILURE AND WRITER'S INVOLVEMENT

In the spring of 1987 similar excessive settlement and lateral deformations were again observed. A new consultant was retained with the writer acting as the designer/technical advisor.

The excessive track deformations observed without catastrophic failure in both 1986 and 1987 indicated a loss of bearing capacity during thaw. Cross trench excavations, illustrated by Figure 8 strengthen this opinion. Figure 8 shows a ballast filled cavity penetrating the sub-ballast surface. Figure 9 shows grading curves obtained on the existing sub-ballast and ballast. The sub-ballast is seen as a dirty gap graded gravel. Frost susceptibility tests classified the sub-ballast as medium frost susceptible for highways and airfields. A worse classification would result for the open nature of a ballasted track and this would be aggravated by the disruption to the drainage from snow, ice build up, or falling logs.

Figure 10. Water filled holes on side with no subdrain.

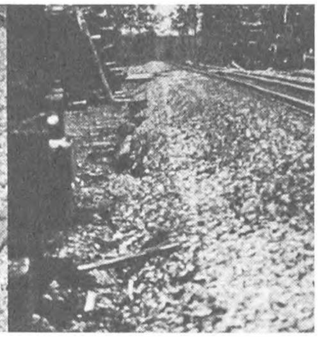

Figure 11. Well drained area above track subdrain.

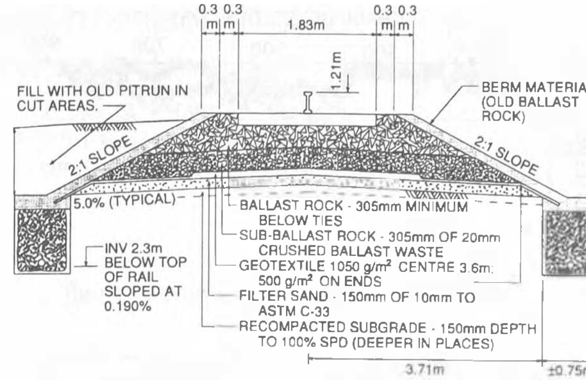

Figure 12. Reconstruction cross section adopted in 1988/9.

It was clear that the track had to be re-engineered.

Confirmation of the poor drainage of surface water is illustrated by comparison of Figures 10 and 11. Figure 10 shows pot holes on the non-drain side of the track made by falling logs that are filled with water. In comparison Figure 11 shows a dry surface on the other side of the same track having a subdrain. Clearly both sides of each track need surface open subdrains.

To prevent subgrade overstressing calculations as outlined by Raymond (1985) showed that a total depth of aggregate considerably greater than 0.75 m would be required. Unfortunately a bridge having about 25 mm clearance existed across the track limited the actual depth to 0.75 m unless heightened. This expense of increasing the clearance was unacceptable to the owner who agreed to take responsibility for any subgrade failure. The owner no doubt assumed that the existing subgrade was not in distress!

Subgrade protection from pumping was recommenued as a 0.15 m layer of concrete sand (graded to the fine aggregate grading of ASTM C-33). The sand surface was to be sloped in accordance with the subgrade slope and covered with a track geotextile in accordance with the specification outlined by Raymond (1994). The geotextile was to be covered by 0.3 m of open graded sub-ballast obtained from the ballast waste (typically crushed 19 mm maximum size grading down to 9 mm minimum size particles) and then with a 0.3 m depth of ballast below base of the ties and in the tie cribs. The ballast was required to have 75 % of particles with three crushed faces, and 95 % with two crushed faces. To be accepted as a crushed face two specified requirements had to be achieved (CP Rail, 1987). The first required the crushed face to have a freshly crushed surface with a minimum width (measured across the crushed surface) greater than 25 % of that particle's maximum dimension (measured between any two of that particle's surface points). The second requirement was that the included angle formed by intersection of the average planes of adjoining fractured faces must be less than 135° for each to be considered as separate fractured faces. The contractor met the specification by crushing locally available 100 mm minimum sized rounded particles. The final cross section designed is shown in Figure 12.

PLANNED 1988/89 RECONSTRUCTION

Track reconstruction was planned in four nearly equal Sections; Section 1 (0+00 to 1+81); Section 2 (to 4+70); Section 3 (to 7+00); Section 4 (to 8+94). The original Mill feed-ins were located on this most northerly Section 1 (Figure 2). This was reconstructed first during the owners annual (summer) vacations along with the movement of logs from the next Section to be reconstructed (i.e. Section 4 the most southerly). Similarly when Section 4 was under construction logs, were moved to Sections 1 or 2.

As the sub-ballast was removed it was noted that the subgrade soil was disturbed to a depth of about 100 mm, as seen in Figure 13. Below the 100 mm thickness of disturbed clay were slickenside shear surfaces formed on relatively firm clay. Clearly insufficient granular cover had existed either after the ties had settled during thaw or in the original design. Deep scarifying and recompaction ensured a strong subgrade.

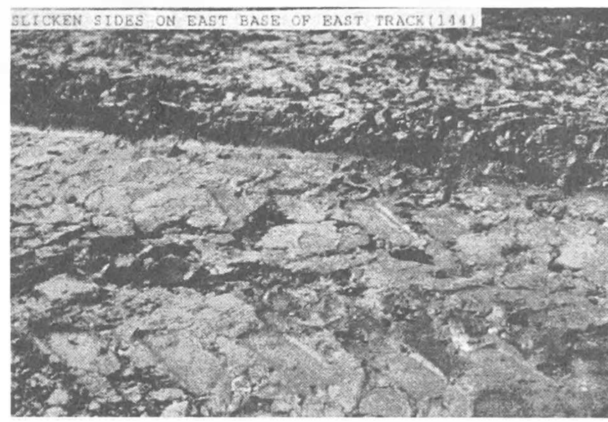

Figure 13. Example of subgrade with slickenside horizons.

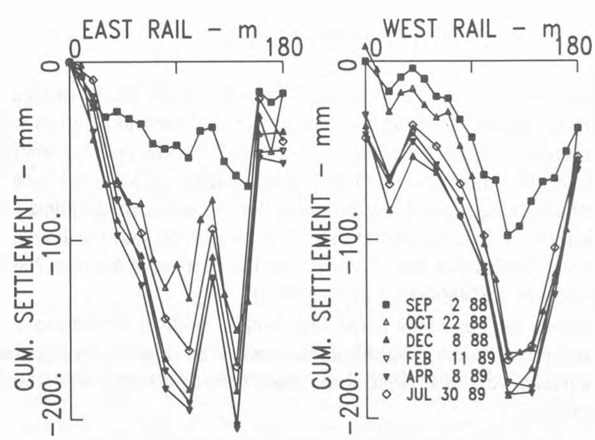

Figure 14. 1988/9 Section 1 cumulative settlements.

GEOTEXTILE SAVES SECTION 1

During the construction of Section 1 weather delays occurred resulting in the owner requesting the contractor to work 36 hours non stop to allow mill operations to resume on schedule. In the process of night work poorly crush aggregate stockpiled for use in the subdrains was accidently used for the sub-ballast (both materials were graded but not crushed the same). On starting use of the newly constructed Section 1, track lateral instability was immediately noted. This was occurring in the middle of summer.

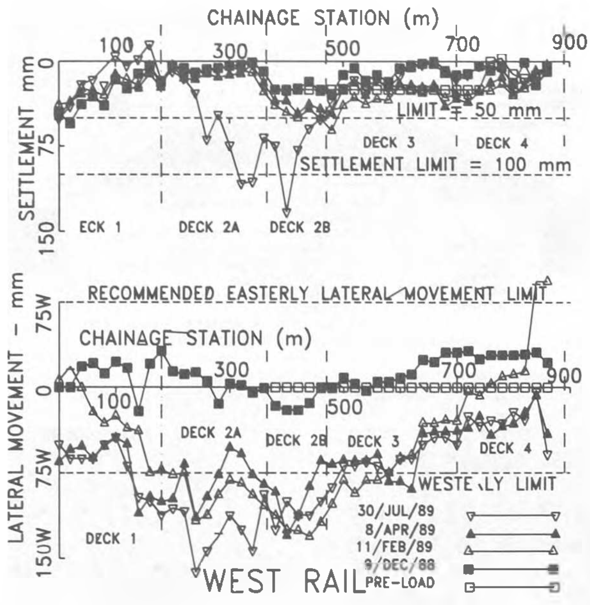

Figure 15. 1988/9 vertical and lateral deformations of west rail.

Once the mistake was discovered the contractor agreed to correct the fault at no cost to the owner. Immediate replacement was unacceptable. The owner had to feed the Mill. It was agreed to re-level the tracks of Section 1 as soon as a settlement of 75 mm was reached. Cumulative settlement readings for Section 1, measured until Section 1 was repaired, are shown in Figure 14.

SECTIONS 2A AND 1 REHABILITATION

With the new Mill in operation Section 1 had lost its strategic importance and the bridge at the former Mill feed-in location was no longer required. Calculations showed that the poorly crushed aggregate drain material placed as sub-ballast in Section 1 would perform reasonably if covered with 0.45 m of crushed ballast (an addition of 0.15 m thickness). This was done and the increase ballast depth taper this down across the portion of Section 2 still to be rebuilt (Station 1+81 to 3+66).

Because the geotextile acted functionally both in separation and reinforcement, no subgrade failure occurred despite the fact that the tracks were re-levelled three times before Section 1 was finally corrected.

FROST FAILURE IN 1989

Due to weather delays during the 1988 reconstruction, winter was setting in as Section 3 was completed. The owner was advised to delay construction of the last section (Section 2) to the summer of 1989. With the observed beneficial performance of the crane in Section 1 the owner decided to build a new larger Mill near the centre of the tracks (just north of Section 3). Based on an expectation of the normal start of freezing weather, the owner decided to proceed with construction of the southern 104 m of Section 2 in 1988 (3+66 to 4+70), designated Section 2B.

Winter set in earlier than normal subjecting the subgrade to freezing temperatures during placement and compaction of all aggregate layers, preventing further beneficial compaction of the subgrade. By the spring of 1989 the (new) Mill feed-in was located in Section 2B. As thaw occurred major settlement were observed over the full length of Section 2B and particularly, as seen in Figure 15, over the 45 m of track adjacent to the Mill feed-in. Reconstruction was limited to the 45 m of track adjacent to the new feed-in. Due to the importance of the feed-in location the reconstruction of this failed 45 m section of track was rebuilt using a geosynthetic aggregate confinement (geocell) layer placed with a clearance of 0.2 m between the top of the geosynthetic and the base of the ties.

RECONSTRUCTION PERFORMANCE

Figure 14 shows the cumulative settlement in Section 1 involving poorly crushed sub-ballast. These results may be compared with those in Figure 15 for the correctly built sections (Sections 3 and 4). The contrast is striking.

The frozen subgrade thaw failure in Section 2B is clearly evident from the settlements shown in Figure 15. Also evident are the settlements in Section 2A (the Section still to be reconstructed) during ground thawed. The settlements along the rebuilt 45 m of track adjacent to the Mill feed-in location where a geocell ballast confinement was used were very small, ranging from 3 to 11 mm with an average of 4 mm. This may be compared with the settlements shown in Figure 15 for Sections 3 and 4. The comparison shows the benefit of the geocell ballast confinement system. In addition the owners noted increased lateral stability of the track with the geocell and wished the geocell had been used along the whole track.

In 1990 an inspection of the crane was made. The results of the inspection showed considerable damage to the crane. The legs to be up to 160 mm out of alignment. Severe cracks were noted at the pier leg to girder connections. The pier to girder pin was protruding over 25 mm. Considerable wheel flange wear existed on the east side wheel flanges. The quoted repairs to the crane equalled the track reconstruction cost.

CONCLUSIONS

Presented is performance data of a ballasted track for a heavy gantry crane that would indicate evidence of thaw failure in the sub-ballast. The thaw failure caused excessive differential vertical and lateral deformations without causing a catastrophic failure. The track was reconstructed using the cross section shown in Figure 12 and has performed satisfactory when both the ballast and sub-ballast were supplied from a well crushed source.

A short length of track incorporated a geocell ballast confinement system whose top surface was 0.2 m below the base of the ties. Exceptional performance was noted when this additional aggregate containment was incorporated into the design.

Major damage was recorded for the gantry crane's leg to girder welded connections, pin connection and wheel alignment as a result of use on the rough track.

REFERENCES

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Raymond, G.P. 1994. "Durability of geotextiles in railway rehabilitation", *Transportation Research Record No. 1439*, Transportation Research Board, Washington, D.C., pp. 12-19.