Once in position, the rod was withdrawn, leaving the segmented tubing in position. After a period of several weeks, the trench was excavated alongside the tubes to expose them as shown in the figure.

From a study of this, and a number of similar observations, it became clear that in this mode of failure soil movements are as indicated in Fig. 3

The segmented tube technique described can also be used to establish whether or not a subgrade failure is taking place. To do this, columns of segmented plastic tubing are driven into the suspected failure site as described above. After a period of some weeks, the initially straight column of tube segements is probed with a straight rod. The location of an obstruction will indicate a distortion of the column of tube segments caused by an active 'cess heave'.

Figure 7 shows the disruption which is often caused to the track side drainage system as a result of cess heave. The heave can either physically destroy the track side drainage and/or, interpose an impermeable wall between the track and the drainage system, thus rendering it ineffective. Clearly, deprived of its drainage path, the water table within the track can rise resulting in an aggravation of the condition which originally gave rise to the cess heave.

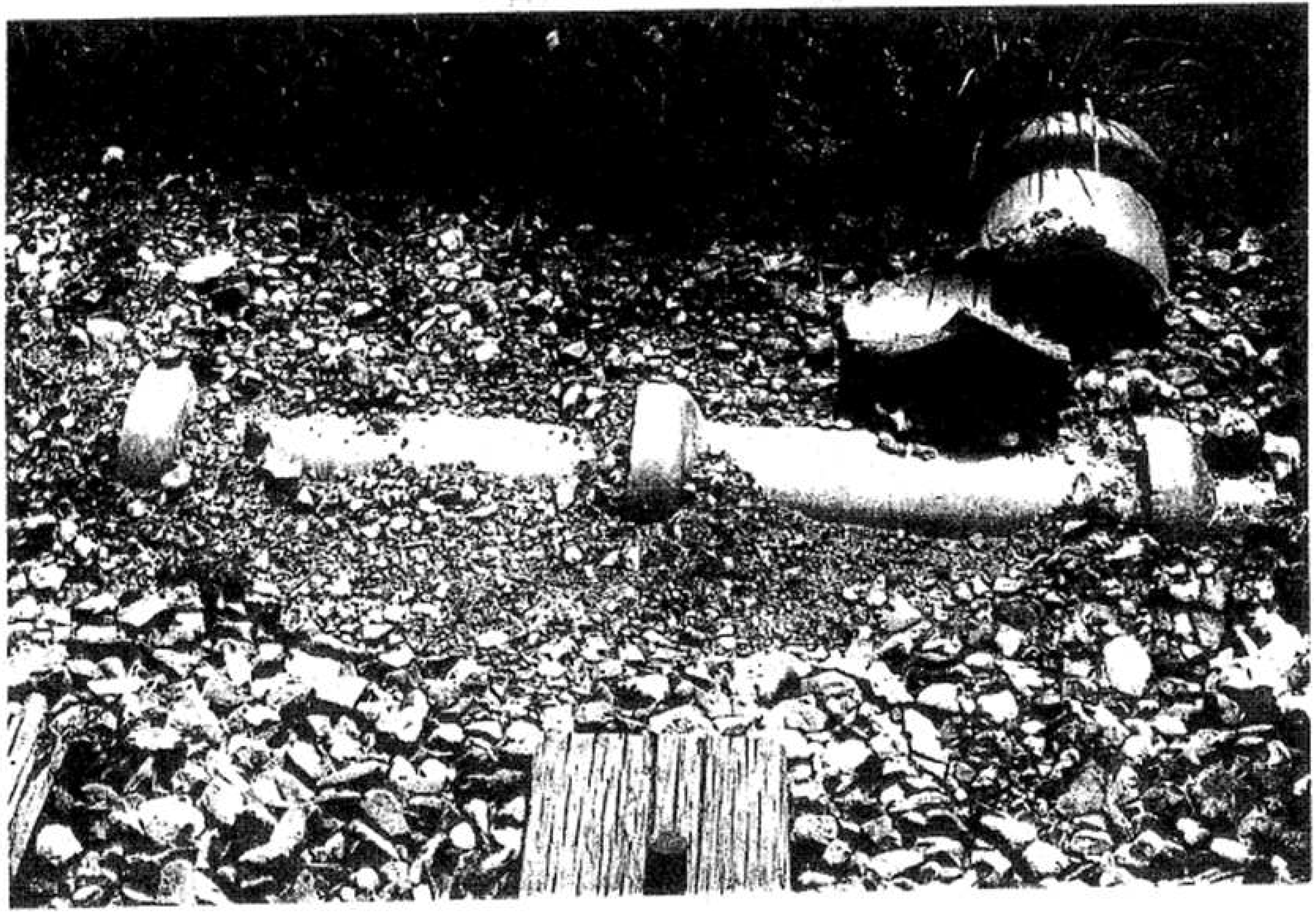

Fig. 7 Disruption of track drainage from cess heave

The probability of a cess heave developing can be minimized by:

- Ensuring that an adequate depth of load distributing (granular) material exists between the underside of the sleeper and the surface of the subgrade.

- Ensuring that the drainage system maintains a low water table level.

As shown in Fig. 3 , the heave of material at the lineside is matched by a corresponding depression beneath the track. This depression is reflected at the surface as a depression in the track, which is corrected by the addition of ballast beneath the track. This measure results in an increase in ballast depth and a corresponding reduction in soil stress at subgrade level which tends to improve stability. However the depression traps water which tends to reduce the potential improvement.

Progressive subgrade failure only occurs in fine grained materials exhibiting low values of internal friction. In coarse grained materials exhibiting high values of internal friction. the increase in shear strength associated with the applied normal stress exceeds the increase in associated shear stress.

If overhead clearances permit, the resistance of the subgrade to a progressive subgrade failure can be achieved by applying a general ballast lift to the track and thereby increasing the depth of ballast between the underside of the sleeper and the surface of the subgrade. This reduces the intensity of stress applied. Such a measure is of value if the stress levels imposed on the subgrade are to be increased; for example, as a result of increased axle loads.

A general ballast lift is not usually an acceptable method for restoring stability following a progressive subgrade failure, since it does not rectify the associated deformations in the surface of the subgrade. Such deformations could interfere with cross track drainage and result in the ponding of water on the surface of the subgrade.

The only solution to the problem could well be the removal of the ballast layer, excavation of the subgrade to a reduced elevation, and replacing ballast and subballast up to its original level. The resulting increase in granular depth will reduce the intensity of stress applied to the surface of the subgrade.

If these measures are utilized, it is usual to use the opportunity to replace or install a subballast layer of blanketing material to prevent future local subgrade failure.

Attrition

As is indicated in Fig. 8 attrition (local subgrade failure) of the subgrade by the overlying ballast in the presence of water can result in the formation of slurry at the ballast/subgrade interface. Under certain conditions, cyclic loading associated with passing traffic can cause this slurry to be pumped up to the surface of the ballast. Such failures are normally associated with hard, fine grained materials such as clay, and soft rocks, such as chalk.

Figure 8 A shows the sleeper resting in a bed of ballast which overlays a hard, fine grained subgrade material. The surface of the standing water is above the surface of the subgrade. Figure 8 B shows how the slurry formed at the ballast/subgrade interface has been pumped to the surface of the ballast. Figure 8 C shows a layer of blanketing material (subballast) interposed between the ballast and the subgrade as a means of preventing the occurrence of subgrade attrition failure.

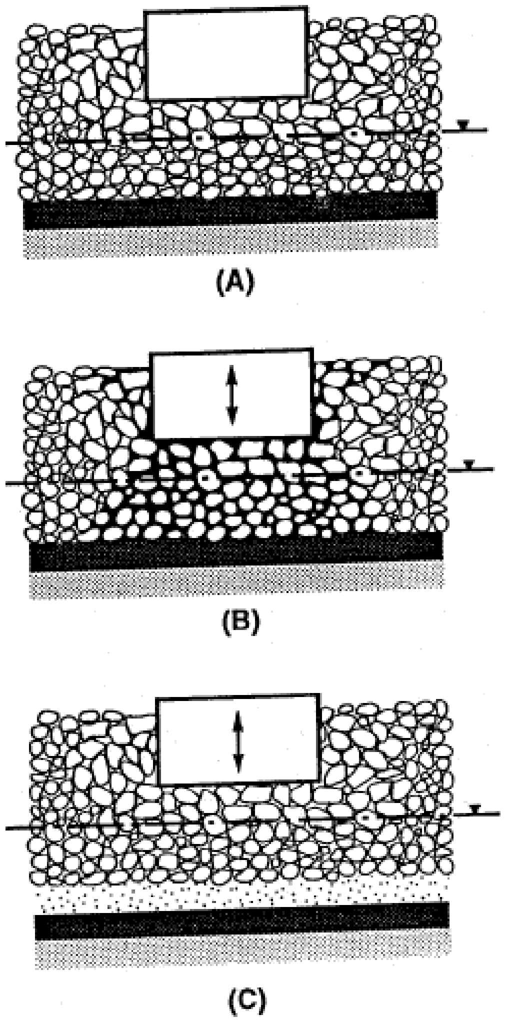

Fig. 8 Cause and prevention of subgrade attrition

As shown in Fig. 9 , when the slurry reaches the sleeper/ballast interface, cyclic movements of the sleeper within the ballast bed result in the slurry being ejected from beneath the sleeper on to the surface of the ballast to give the condition known as "Pumping". The slurry, in this case from subgrade attrition, ultimately finds its way into the trackside drainage system which can result in premature blocking.

The surface manifestations of a pumping failure are very similar to those associated with ballast/sleeper erosion and/or the presence of dirty ballast around the sleeper. Its cause and its cure are however quite different. An examination of the fine grained materials present in the slurry can usually indicate its source and hence the type of failure being encountered.

Fig. 9 Pumping of slurry from subgrade attrition

Because of its association with high subgrade stresses and large sleeper movements, subgrade attrition failure is frequently found to originate at sleepers associated with rail joints.

Local subgrade failures accompanied by pumping can lead to a loss of lateral track restraint, which in turn can lead to a loss of correct horizontal and vertical track alignment, as a result of:

1) Displacement of ballast from around the sleeper by the jetting action of the slurry during ejection from beneath the sleeper.

2) Lubrication of the ballast/sleeper interface resulting in a reduction in sliding friction between the sleeper and the ballast.

3) Lubrication of the ballast particles resulting in a reduction in the shear strength of the supporting and shoulder ballast.

4) A local depression of the subgrade resulting from a loss of material associated with the erosion of the subgrade, and possible ponding of water within the depression.

Pumping failures can be prevented by placing a layer of blanketing material between the ballast and the subgrade as shown in Fig. **8** to:

1) prevent the formation of slurry by mechanically protecting the fine grained subgrade from attrition and penetration by the overlying coarse grained ballast, and

2) prevent the upward migration of any slurry that forms at the subballast/subgrade interface, by virtue of the filtering properties of the subballast.

If possible, provide adequate drainage to ensure that the surface of the standing water is maintained below the level of the ballast/subgrade interface.

Temporary relief from the problems associated with subgrade attrition failure can be achieved by full ballast cleaning. However, ballast cleaning does not treat the root cause of the problem. A long term solution can only be achieved by placing a subballast layer between the ballast and the subgrade.

As a result of the investigative work undertaken on this subject, and the preventative and remedial works carried out, subgrade attrition failures on British Railways are now a rare occurrence.

Subgrade Settlement

Subgrade settlement can result from several causes:

1) Consolidation from weight of added earth or from ground water lowering (or conversely swell from removal of earth as in cut construction or ground water rise).

2) Shrinkage from moisture loss (and conversely swelling from moisture increase).

3) Underlying ground subsidence from sources such as mining and solution cavities.

4) Progressive deformation from repeated traffic induced stresses.

Consolidation settlement (or heave) can be analyzed and solutions provided by well-established methods of geotechnical engineering. Closely associated with consolidation is volume change from moisture content change. However consolidation involves expulsion of pore water from saturated soils, whereas shrinkage involves loss of water from unsaturated soils. Swelling and shrinking of soils is also a subject which is well known in geotechnical engineering practice.

Underlying ground subsidence problems also fall within normal geotechnical engineering practice.

Mechanisms of plastic deformation in the subgrade from repeated loading include: 1) volume reduction (compaction), 2) consolidation when repeated stresses cause pore pressure increase, and 3) shear deformation. Shear deformation associated with pore-pressure development is related to progressive shear failure

. A fourth mechanism is ballast void infiltration by subgrade particles due to a lack of a filter layer with resulting track settlement. This is a different problem than the problem of subgrade attrition with slurry formation. A proper subballast layer will solve this problem.

Settlement is usually nonuniform along and across the track. Hence excessive subgrade settlement can lead to unacceptable track geometry change. The wavelength of the geometry change depends on the source of the settlement and its pattern.