# Rail Corrugation—Experience of U.S. Transit Properties

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ABSTRACT

Rail corrugation is a common problem with all rail transit systems. Presented in this paper is information received from various U.S. transit properties in response to a questionnaire prepared on this subject and circulated in early 1985. This questionnaire requested information concerning track geometry, type of track support, and structure type where corrugation is being experienced. Information was also requested on the characteristics of rail and wheel wear as well as remedial action taken to alleviate the problem. The information received was presented at the subsequent Rail Corrugation Workshop at the June 1985 American Public Transit Association (APTA) Conference in Atlanta, Georgia. Other papers presented at this workshop discussed parameters influencing rail corrugation and current understanding of the rail corrugation phenomenon. Discussed in these papers were (a) recent studies conducted by the U.S. Department of Transportation through its Transportation Test Center at Cambridge, Massachusetts; (b) studies recently performed on the Fast Track at Pueblo, Colorado; and (c) the results of recent tests performed by the Budd Company Technical Center on the Port Authority Transit Corporation (PATCO) system at Camden, New Jersey. In summary, rail corrugation is a matter of concern for all rail properties. No rail system is immune to the corrugation problem. It was the conclusion of all participants in the rail corrugation workshop that there is a need for a more unified approach to organizing and funding a coordinated research effort to bring together the various groups currently studying the many aspects of rail wear and rail corrugation.

All operating U.S. rail transit systems have experienced problems with rail corrugation. It has been estimated that yearly maintenance dollars expended in North America for rail grinding and corrugation control exceed $1 million. Actual operation of the new rail system in Baltimore began in November 1983. It became apparent almost immediately that Baltimore was no exception because by December, rail corrugation had developed on the sharp curves in the underground section.

The immediate question was "What went wrong?" Information was requested from other rail properties and an assessment of the problem was made. (Because this assessment preceded and influenced the industry survey, the Baltimore problem will be discussed first.)

The track in the underground sections is attached to the concrete tunnel inverts by direct fixation and, in areas deemed sensitive to ground-borne vibration, by direct fixation to floating slab or Stedef two-block concrete ties, or both, supported in rubber boots. The initial corrugation was observed to develop in the sharp curves (750- to 1,000-ft radius) in the downtown section. This section contains both direct-fixation track and the Stedef two-block tie system. At that time, the corrugation was developing within the two-block tie section, but not in the adjacent direct-fixation section. This rail corrugation phenomenon has since also spread into the direct-fixation sections. Also, noticeable corrugation has developed on a section of track on a 4 percent descending grade leading inbound from the portal. This section is also located on direct-fixation track and exhibits flow of metal in the direction of travel and away from the gage-side of the track surface.

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Rail grinding has been employed as the only way to control the corrugation propagation in the Baltimore system. To properly control noise levels, grinding is required at frequent intervals. The criterion for grinding has been the intensity of the noise or "roar" that is developed as a train passes over a section of corrugated track. Because of restraints in scheduling grinding equipment, the frequency has been limited to three times during the 2 years of operation.

As part of the author's review of the corrugation problem in the Baltimore system, the Maryland Mass Transit Administration (MTA) prepared a questionnaire on the subject, which was sent out to 12 rail transit properties within the United States (Baltimore included). Responses were received from 11 agencies, 10 of which reported corrugation problems and associated low-frequency noise levels. One property, Boston, reported no rail corrugation problem. It is the author's understanding that some rail corrugation does occur on the Boston system. The Massachusetts Bay Transportation Authority (MBTA) does use restraining rail and rail lubrication to control rail wear, however, and this may be a factor in minimizing the rail corrugation problem.

The questionnaire requested information concerning geometry, type of track support, structure type, track gage, type of rail, and characteristics of rail and wheel wear. Information was also requested on remedial action taken. (Note that the questionnaire and a copy of all information obtained are available from the author if requested.) A summary of the responses is given in Table 1. Information was also received concerning the types and characteristics of the vehicles used on the various properties. This information requires further refinement before being incorporated into this study.

The properties did report on remedial actions taken to control rail corrugation problems. Rail

TABLE 1 Questionnaire Responses

| Questionnaire Category | Number of Transit Property Responses |
|---|---|
| Track geometry (where the problem occurs) | |
| Tangents | 6 |
| Curves | 10 |
| Corrugation occurs on curves | |
| Radius under 500 ft | 2 |
| Radius under 1,200 ft | 4 |
| Radius under 2,000 ft | 1 |
| All curves | 3 |
| Low rail only | 3 |
| High rail only | 1 |
| Both rails | 6 |
| Track gage in curves | |
| Maximum of 4 ft 8½ in. | 4 |
| Maximum of 4 ft 8¾ in. | 4 |
| Maximum of 4 ft 9½ in. | 1 |
| Type of track support | |
| Wood ties on ballast | 7 |
| Concrete ties on ballast | 2 |
| Direct fixation on concrete slab | 7 |
| Dual block concrete ties on slab | 3 |
| Type of structure support | |
| Aerial with concrete deck | 7 |
| Aerial with open deck | 5 |
| Concrete slab on grade | 7 |
| Tie and ballast | 4 |
| Type of corrugation experienced | |
| Wave length <2 in. | 5 |
| Wave length 2 in. to 4 in. | 2 |
| Wave length 4 in. to 6 in. | 2 |
| Wave length >6 in. | 2 |
| Type of rail used | |
| 100 lb | 4 |
| 110 lb | 1 |
| 115 lb | 5 |
| 132 lb | 1 |
| Special rail in curves | |
| Control cooled | 10 |
| Heat treated | 4 |
| Special alloy | 1 |
| Vehicle characteristics | |
| Cylindrical | 6 |
| Conical | 6 |
| Significant wheel wear | 6 |

grinding was performed by nine properties and was considered by the tenth. Frequency of grinding was from 6 to 24 months with three properties listing "occasional." Rail lubrication is utilized by all responding properties except Baltimore. Wheel modification has been employed in Washington, gage widening has been reported by San Francisco, and the use of restraining rail has been reported by Cleveland. Although many of the reported modifications were considered for other purposes, they do affect the problem of rail corrugation.

The preceding information was presented as part of a workshop on rail corrugation at the Rail Conference of the American Public Transit Association (APTA). Although it is sufficient to indicate some measure of the existing problem, it is obvious that few conclusions can be derived from these data in their present form. Three other papers were also presented for discussion at this workshop that addressed the results of other related research and recent investigation into the subject by the individual authors (1-3).

Sluz presented the results of studies performed and data collected by the Transportation Systems Center and information developed for related research studies by other investigators (1). The parameters influencing rail corrugation as defined in his paper are as follows:

- Rail hardness,
- Lubrication,
- Fastener stiffness,
- Fastener spacing,
- Truck superelevation,
- Restraining rail,
- Rail and wheel roughness, and
- Truck parameters.

In summary, the paper concludes that

> [...] it is clear that as of yet no unified hypothesis exists that can fully explain the initiation and propagation of rail corrugations although several promising theories do appear to explain at least some of the aspects of the phenomenon. In truth, there are probably a myriad of vehicle and track parameters which combine to produce corrugations. Whether corrugations appear and their severity if they do, depends upon the extent to which these parameters superimpose to exacerbate or mitigate the stresses operating on the surface of the rail.
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> Each transit system may have its own unique conditions which lead to corrugations and in the absence of a valid general theory to help identify the particular set of parameters responsible for corrugations on its own system, may need to resort to trial and error to effect a solution. Much work has been done in this area - much more needs to be done. As a minimum, more communication among transit systems is needed to publicize what has been attempted, what has worked, and what has failed.

The research conducted by Daniels was performed at the FAST Track, in Pueblo, Colorado, and was designed to simulate the normal operation of a North American freight railroad with the objective of determining factors affecting rail corrugation growth and evaluating grinding methods to reduce corrugation growth (2). These tests have generated significant results pointing to an understanding of the corrugation phenomenon, including the effects of track vibration and wheelset/rail interaction. The report reviews specific factors such as higher-strength steel, rail lubrication, and increased wheel/rail contact areas that tend to minimize and control corrugations. Implications are discussed for track maintenance and materials.

Mekosh describes the progress being made at the Budd Company Technical Center in the area of wheel/rail dynamic simulation (3). Much of this work was started at the Technical Center during the steerable-axle truck development program and, more recently, in support of a test program that was conducted at Port Authority Transit Corporation (PATCO). The principal objectives of the recent test program were to predict and measure the wheel/rail curving forces for three distinctively different truck configurations, the standard Budd P-III truck in operation at PATCO since 1969 and referenced as the baseline for comparison, the standard P-III truck equipped with soft suspension bushings in revenue service since 1982, and the experimental steerable-axle truck also in revenue service since 1982. Budd's nonlinear rail-vehicle, dynamic simulation model is being used to simulate these force oscillations using various friction versus creepage characteristics. Listed in the paper are several preliminary conclusions that may be drawn from the present data. These conclusions are listed in part as follows:

- A lateral friction-versus-creepage characteristic that drops off after reaching a maximum value is a major contributor to computer-generated lateral force oscillations.

• The combination of the lateral stiffnesses of the track support system and the truck primary suspension affects the amplitude and frequency of the lateral force oscillations.
• Steerable-axle trucks negotiate curves essentially in the radial position, which, in turn, reduces the lateral creep force to near-zero levels.

In conclusion, rail corrugation is a matter of concern for all rail properties. Present information indicates that rail corrugation costs the American Railroad Industry an estimated $100 million annually. Annual costs to transit systems in North America for rail grinding alone exceed $1 million. No rail system is immune to the corrugation problem.

Rapid growth of rail corrugation and the demand for track maintenance are related in that both are the result of exceptionally high forces resulting from the dynamic interaction of the rail and wheels with the operation of the system. Although many factors have been identified as affecting the development of corrugation, not enough is presently understood of the interaction between these factors and the forces that create rail corrugation. Further study is needed to better understand the interaction of these many factors as a unified system so that design guidelines may be established. These guidelines will assist designers in developing criteria for the design of track systems and vehicles so that corrugation and other track wear phenomena may be minimized. This same knowledge should be beneficial in better directing maintenance action to control the problems that do develop. There is a need, however, for a more unified approach to organizing and funding a coordinated research effort to bring together the various groups currently studying the many aspects of rail wear and rail corrugation.

## REFERENCES


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