PROJECT: LFST

SUBJECT:

Discussions with Railroad Engineers

S. von Hoerner

For large telescopes, one of the possibilities for the azimuth rotation is a circular track on the ground, with a diameter comparable to the diameter of the telescope. A substantial fraction of the total costs, then, would be in these foundations. The costs would be reduced considerably, if just normal plain railroad could be used for the azimuth rotation: standard roadbed, ties and rails, and standard freight cars (without springs). The main question is whether it can be used concerning the accuracies we need.

In my first antenna paper (June 1965), I gave some estimates based on a telephone call to a railroad firm. With a maximum load of 30 tons/axle (450 tons/100 feet), the costs were mentioned with $ 80,000/mile; the accuracy after one year of normal use by trains was quoted with ±1/2 inch. For comparison, Bill Horne at Green Bank estimated the costs of a single heavy steel track, embedded in concrete and anchored to the ground, taking 300 tons downward and 80 tons laterally and upward; the result was $ 700,000/mile.

In order to obtain better estimates on railroads, I had several discussions on Aug. 29 with five railroad engineers of the New York Central System (466 Lexington Ave, New York, N.Y.). This meeting was suggested and prepared by J. Hungerbuhler. The results are given in the following.

1. Mr. Cunningham (General Discussion)

The ballast (gravel) used for the roadbed is not really "solid"; it provides for trains a certain (desired) "cushion", moving about 1/2 inch down if a train drives over it. If more rigidity is wanted, or if the ground yields too fast, a consolidation is used for the lower part of the roadbed by grout (mixture of sand and cement) which is poured in under pressure. For details, we should write to the firm Penetryn (38399 Pelton Road, Willoughby, Ohio; close to Cleveland). See attached letters (answer doesn't tell much).

A foundation of solid concrete is not recommended. It would not allow proper adjustments and maintenance, although the ground beneath it still would yield slowly. A really stiff and solid concrete foundation, thus, would need many pillars driven down to greater

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depth, if possible to solid rock; this would become extremely expensive.

Modern railroads mostly have welded rails, where the temperature stresses are taken up by the ties to the ballast. (Older rails leave open gaps between rail ends of about 1/8 to 1/4 inch.)

2) Mr.D.Perish (Costs)

For the complete track section (ballast, ties, tracks), for heavy loads, one has in the average about \$ 15/foot for the material, and \$ 1.5/foot for the labour; but the last figure might be about double for a small job, not connected to an existing railroad. In addition, one has about \$ 1-2/yard^3 for grading (soil movement). On normal, relatively level ground, the total is about

\$ 20/foot = \$100,000/mile.

3) Mr.H.Curtis (Loads)

For heavy tracks (weight of (single) track 100 - 136 lb/yard), and for 21 inches between centers of ties, the maximum (downward) load is

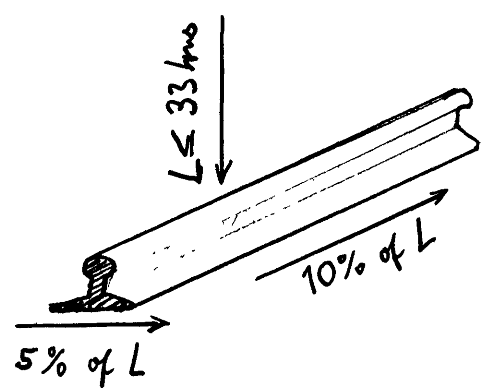
72,000 lb/axle = 33 tons/axle (two wheels).

With a minimum spacing between axles of 5 feet, this amounts to

660 tons / 100 feet.

The maximum forces in other directions depend on the load actually present:

10 % longitudinal (like accelerating a train)
5 % lateral (like a train in a curve).



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4) Mr. T. Scott (Maintenance)

For pssenger trains up to 85 miles/hour, the accuracy of newly built railway is mostly about 1/4 inch (grade and lateral), more accuracy is not needed. The cushion effect is about 1/2 inch in the average.

For heavy, high-speed trains, maintenance is necessary about every two years. Where the tracks are low, they are lifted, and more gravel is hammered beneath. These adjustments are 1/2 inch average and up to 1 inch; on soft ground occasionally up to 2 inches.

The cost of maintenance is about 400 $/mile.

5) Mr. R. Pattison (Welded Rails and Accuracy)

Modern railroads mostly use welded rails. The rails are anchored to the ties; the ballast reaches to the level of the top edges of the ties and it extends at least two feet sideways beyond both tie ends.

The maximum accuracy to be achieved by standard methods, for building and maintenance, is 1/8 inch (grade and lateral), and the cushion effect can be brought to 1/4 inch under heavy trains if wanted small.

The consolidation by grout would increase the costs by about 15 per cent.

For details and measurments on welded rails, we should write to the American Railway Engineering Association, Committee on Welded Rails, 59 Van Buren Street, Chicago, Ill. I have written, see attached letter, but no answer yet.

If some length of roadbed is produced with the same gravel and the same method on about the same soil, then the cushion effect, even after one year of use, should be about constant along this length of roadbed; within, say, 20 or 30 per cent.

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Summary and Conclusions

1. We could use either just normal roadbed with maintenance every two years, or reinforced concrete foundations on concrete pillars driven far down; but nothing in between. - The following holds only for normal roadbed.

2. Costs are about 100 000 \$/mile for erection, and about 400 \$/mile for maintenance.

3. Consolidation by grout only to improve soft ground.

4. Maximum loads. 4a. Down: L = 33 tons/axle = 660 tons/100 feet.
For example, a structure of 6000 tons should sit on at least 200 axles; this means 50 heavy gondolas with 4 axles and 35 000 \$ each, which gives 200 000 \$. The weight must be distributed over at least 1000 feet of track, which is the case, anyway.

4b. longitudinal = 10 % of L
lateral = 5 % of L

For example, a telescope of 200 m diameter, with a face-on wind of 25 mph, gives a wind force of 400 tons. If longitudinal only, the weight (telescope, gondolas ...) then must not be less than 4000 tons. If lateral, the weight must not be less than 8000tons.

The flat transit telescope will pick up about 2000 tons wind force in survival (110mph) which calls for some special anchoring in stow position. During observation, 25 mph, the wind force is 100 tons, which, even if lateral, demands only 2000 tons of weight which is the case anyway.

It seems that weight and wind force impose no serious problems.

5. Accuracy with standard methods can be brought to 1/8 inch for erection and maintenance, and is 1/2 inch after one year or two of use with fast trains. Regarding our low speeds, one might assume 1/4 inch = 6.34 mm.

If the tracks have the same diameter as the telescope, and demanding a pointing accuracy of 1/16 of a beamwidth, standard railroad is good for $\lambda = 10 \text{ cm} \sqrt{2/n}$, since we subtract two deformations at opposite sides of the track, and if the structure averages over n independent deformations on either side. We might suggest to regard $\lambda = 5$ cm as the limit. (Especially, if the surface gets deformed, too.)

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TELEPHONE 304-456-2011

EDGEMONT DAIRY ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 703-296-0211

September 2, 1966

American Railway Engineering Association
Committee on Welded Rails
59 Van Buren Street
Chicago, Illinois

Gentlemen:

The National Radio Astronomy Observatory maintains a working group to investigate the possibilities of the "Largest Feasible Steerable Telescope " (LFST). Some of the designs studied would require, for rotation in azimuth, a circular track horizontally on the ground, with a diameter between 500 and 1500 feet. The question was raised whether a normal railroad could be used for that purpose, in order to keep the costs as low as possible.

We would like to ask you several questions with respect to welded rails and their performance. We would be very grateful if you could help us by answering these questions (at least in the form of rough estimates), in order to give us a general picture about this possibility.

The following questions assume that we had built a circular railroad of, say, 1000 feet diameter, with welded rails on ties and ballast, for heavy loads of, say, 72,000 lb/axle.

1) Concerning temperature differences (summer and winter, or day and night):

   a) What is the expected amount of horizontal and vertical buckling?

   b) What is the expected average displacement (change of diameter)?

2) What are the maximum allowed loads in directions

   a) longitudinal to the rails (as for the acceleration of a train),

   b) lateral to the rails (as for a train in a curve)?

3) What is the average deformation after one year of normal use?

4) What is the average cost per mile of railroad?

Looking forward to your answers,

Yours sincerely,

Dr. S. von Hoerner

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TELEPHONE 304 - 456 - 2011

EDGEMONT DAIRY ROAD
CHARLOTTESVILLE, VIRGINIA 22901
TELEPHONE 703 - 296 - 0211

September 2, 1966

Penetryn Co.
38399 Pelton Road
Willoughby, Ohio

Gentlemen:

The National Radio Astronomy Observatory maintains a working group to investigate the possibilities of the "Largest Feasible Steerable Telescope" (LFST). Some of the designs studied would require, for rotation in azimuth, a circular track horizontally on the ground, with a diameter between 500 and 1500 feet. The question was raised whether a normal railroad could be used for that purpose, in order to keep the costs as low as possible.

We would like to ask you several questions with respect to consolidated roadbeds and their performance. We would be very grateful if you could help us by answering these questions (at least in the form of rough estimates), in order to give us a general picture about this possibility.

The following questions assume that we had built a circular railroad of, say, 1000 feet diameter, with rails on ties and ballast, for heavy loads of, say, 72,000 lb/axle.

1. There is a so-called "cushion effect" (elastic deformation, when a heavy train drives over the tracks);

   a) How large is it in the average for normal roadbeds?

   b) How large is it if the roadbed has been consolidated by grout?

2. After one year of normal use, the tracks will show some permanent deformation (mostly by the settling and yielding of ballast and ground);

   a) How large is the average deformation for normal roadbeds?

   b) How large is it if the roadbed has been consolidated by grout?

3. Usually (if I understand it right), only the lower part of the roadbed is consolidated, since a certain amount of cushion effect is desired for trains. If we would prefer a roadbed as rigid as

as possible,

a) Could one use consolidation right up to the ties?

b) What advantage would it yield?

c) What disadvantage could result (maintenance, adjustments ...)?

4. What is the average additional cost per mile of roadbed for the consolidation?

Looking forward to your answer,

Yours sincerely,

Dr. S. von Hoerner

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PENETRYN SYSTEM INC.

38399 PELTON ROAD
WILLOUGHBY, OHIO 44094
TELEPHONE (AREA CODE 216) 946-4450

September 12, 1966

Dr. S. von Hoerner
National Radio Astronomy Observatory
Post Office Box 2
Green Bank, West Virginia 24944

Dear Sir:

Your letter of September 2, requesting information on roadbed consolidation raises some interesting questions which, I am sorry to say, we cannot answer in a way which will be of much assistance to you.

The pressure grouting of railroad roadbeds is generally done only in locations of extreme distress where water pockets cause pumping action or in unstable or sliding fill areas. The object of the cement grouting is to correct these conditions. To my knowledge track grouting has not been used to increase load capacity of bearing soils in themanner you are investigating.

The feasibility of pressure grouting in your proposed application would very much depend upon the existing soil conditions. Cementitious grouting would be effective only in areas where voids or coarse aggregate exist; however, chemical grouts may be utilized in stabilizing most soils. Literature is enclosed on chemical grout procedures.

I do not have answers to your questions 1(a) and 2(a). However, the effect of a grouted roadbed in your questions 1 and 2 would normally be small if the bearing soils are good, as the cement grouting would generally be executed only to consolidate unstable areas below the roadbed. Chemical grouting might be employed to increase load capacity, in bearing areas in your situation, however.

Consolidation of a roadbed up to the ties (question 3) would, in normal construction, fill all ballast voids and, in effect, result in an unreinforced concrete slab. This slab would be subject to cracking and breaking up and would be unsatisfactory, in my opinion. A rigid base of heavily reinforced concrete with an adequate bearing foundation would be more practical.

All costs of roadbed consolidation are based, as I have mentioned, in distress areas. I am sure you would be selecting an area of sound bearing conditions for the telescope location, and these cost figures would be of little help to you.

More technical information regarding track and roadbed action under various conditions can probably be obtained from the Association of American Railroads. I would suggest you write to Mr. G. M. Magee, Director of Engineering Research, Research Center, 3140 South Federal Street, Chicago, Illinois 60616.

Yours very truly,

THE PENETRYN SYSTEM, INC.

Earl R. Blewitt
Executive Vice President

ERB:ps
Encl.

ASSOCIATION OF AMERICAN RAILROADS
RESEARCH DEPARTMENT

RESEARCH CENTER
3140 SOUTH FEDERAL STREET
CHICAGO, ILLINOIS 60616
CALUMET 5-9600

W. M. KELLER, VICE-PRESIDENT
G. M. MAGEE, DIRECTOR OF ENGINEERING RESEARCH

October 3, 1966

Dr. S. von Hoerner
National Radio Astronomy Observatory
Post Office Box 2
Green Bank, West Virginia 24944

Dear Dr. von Hoerner:

I am sorry I have been so long in replying to your inquiry of September 2 addressed to the American Railway Engineering Association in which you asked several questions regarding construction of railroad trackage for the "Largest Feasible Steerable Telescope." The following is in response to your questions as numbered--

1a) The coefficient of expansion of rail steel is .0000065. The temperature differences will depend upon the location. In the Chicago area the extremes in rail temperature would be from about 140°F in hottest summer to -20°F in coldest winter. If the rail were free to expand lengthwise, you could calculate change in length by multiplying the circumferential length by the coefficient of expansion and the degrees temperature change from the laying temperature. Actually, if this rail were laid in track continuously welded for the entire length on the conventional type of track structure used in the United States with rail anchors boxed on each side of each alternate tie, there would be no change in length or change in diameter of the circular track with this temperature change. We have found that the holding power of the ties in the ballast and rail fastenings is such that the rail can be maintained in position throughout this temperature change without any change in length if the rail is laid at about a mean temperature. This means, of course, that thermal stresses are developed in the rail; tension in winter, and compression in summer. The stresses so developed are equal to 195 lbs. per square inch of rail cross section per degree Fahrenheit temperature change from the laying temperature.

1b) Answered in the above.

2a) This is difficult to answer as this is seldom a problem. We operate regular trains where tractive forces behind a number of diesel units of as much as 250,000 lbs. are developed without any difficulty. I can not foresee any condition where this would present a problem to you.

2b) The lateral load that conventional railroad track will withstand depends upon the weight of the loading applied to it. For example, unloaded track can be displaced sideways with a lateral force applied at one point on one rail of 12,000 lbs. With a loaded car weighing 114,700 lbs. on the track, a lateral force of 38,000 lbs. is required to displace the track under one truck. If a conventional wheel is used, a ratio of lateral to vertical force applied to the rail of 1.00 should not be exceeded to prevent flange climbing or turning the rail over. You do not inquire regarding the maximum vertical loading. I assume that for the use you will be making of this trackage the movement will be slow and passanges will be relatively infrequent. On this basis, using a 36 in. diameter wheel, I would consider an axle loading of 50,000 lbs. would be satisfactory.

3) We have no specific information on this and it would depend to a great extent upon the quality of the roadbed construction, depth and kind of ballast, etc. If the roadbed is formed in accordance with best known technology for soil selection and compaction and at least 8 in. of good quality subballast and 8 in. under the ties of a good quality of top ballast are used, I would doubt that you would have more than 1/4 in. settlement at any location after a year's use, after the ballast is compacted.

4) The average cost will depend upon the type of track construction. For a heavy type of best quality track construction, the following figures will give you some idea of the cost--

Average cost per mile:
Rail, 132 lb., 233 net tons at $125.00--$29,200 plus freight.
Welds, 270 at $12.00--$3,240.
Rail anchors, 6,400 at $0.50--$3,200 plus freight.
Tie plates, 6,400 at $1.50--$9,600 plus freight.
Spikes, 25,600 at $0.10 each--$2,560.
Ties, 3,200 at $5.00--$16,000 plus freight.
Ballast, 3,000 cubic yards of subballast at $1.50--$4,500 and 3,000 cubic yards of top ballast at $3.00--$9,000.
Cost of laying track--$15,000.
The cost of roadway will be entirely dependent upon the terrain and it would be impossible to give you a figure on this that would be of any value.

I assume you are planning on conventional two-rail track construction. I would recommend this in preference to a single rail construction on short ties. I hope the foregoing will give you the information you need.

Very truly yours,

GMM:at
cc: Mr. E. W. Hodgkins, Executive Secretary
American Railway Engineering Association