TRACK CONSTRUCTION

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As a survey draftsman and engineering surveyor, my work has been guided by the maxim of the survey profession of "working from the whole to the part". Taken out of its cryptic phraseology, this means seeing the survey as a whole in the first instance, determining the baselines within which the task is to be confined, and then setting out the parts or details of measurement by which the survey is judged complete.

Such a policy can be related to the construction of a tramway track, and indeed the application of an engineering survey to a project of this kind will mark the distinction between an amateur or professional standard in the finished article.

This is the result I endeavoured to achieve in my supervision of the track construction for the Australian Electric Transport Museum (South Australia) Incorporated at St. Kilda, South Australia in 1973. I believe that, allowing for the vagaries in the materials used and the type of labour employed, the criteria was met.

Following on the successful conclusion of that project, I feel honoured to be asked to present this paper to the second conference of the Council of Tramway Museums of Australasia conference knowing that several of the organisations represented in this body are either building or contemplating the laying of an operating tramway track.

In approaching the subject of track construction I would like to mention what I regard as an ideal layout for the tramway depot and yard. Naturally, this will only be possible for a completely new development and even then limited in its scope by topographical or cadastral (boundaries) features. The ideal is one or more dispersed two or three lane sheds capable of holding up to th ree bogie cars on each track. Carefully placed on site, several important conditions are fulfilled.

1. A number of small sheds, whether "jerry-built" or of an approved industrial design, will confine fire loss. (A shed of industrial design is no guarantee against loss if the fire is of internal origin.)

2. For the purpose of shunting, tracks three cars long is the optimum if there is a desire to facilitate the regular usage of a considerable variety of units.

3. A convenient yard layout using "off-the-shelf" railway turnouts of selected angles. These have components of specific dimensions facilitating unskilled assembly. For example: a South Australian Railways standard gauge 1 in 8 turnout with a 15 foot switch has an overall length of 87 feet 9 inches.

In assessing the requirements for the main line certain desirable factors should be taken into consideration. Again, this is more easily achieved in a new development than one already underway where the shortcomings are obvious.

I believe it is important that a museum tramway should "go somewhere". This is important, not only to encourage the public to ride, but also to set a target at which to aim by the museum members building the line. This single conception wants to be quite clear and acceptable to the membership, adjacent land-holders, planning and conservation bodies, municipalities and governments. Track-laying, especially by volunteers, is a labour intensive, arduous and time-consuming occupation. The morale of museum members will quickly decline if, through lack of planning, the track has to be altered significantly after the commencement of the project.

With some idea of "where to go", and therefore a notion of likely public demand for rides, the number of cars needed to meet the traffic should be a guide as to whether the line requires an intermediate loop or loops, or terminal sidings. These features should be logically located, taking into account a suitable site for placement, sight distances, timetabling etc.

The next step is to estimate the amount of material wanted to construct the track. This is where "surveying" of some kind must come into the picture - both engineering and quantity surveying.

If nothing like a naturally flat road bed or disused railway right-of-way already exists at the museum site, a rough reconnaissance survey using a measuring tape, hammer and pickets should first be undertaken. Place the pickets, preferably with a piece of white rag attached for visibility, at the apexes or intersections of the proposed curves, making allowances for the intervening topography (grades), legal boundaries and fences (not always coincident!), and any other physical obstructions such as buildings and trees. "Juggle" these pickets until the optimum available solution is realised. (Main line railway operation requires certain parameters to be observed in the engineering surveys for any particular track construction, for example: maximum grades, minimum radius curves etc. These can be dispensed with in tramway practice so long as commonsense prevails.)

Next, intermediate pickets are arranged on the straights or tangents to enable the line of route to be measured more easily. If it is unlikely that an accurate engineering survey for the track alignment will be done, the magnetic compass bearings of the tangents as observed from the curve intersection pickets, will enable relevant information for the track on the curves to be determined, Keep a proper record of the recce survey as shown on the sketch.

The "legs" can be measured either independently, or as a "running chainage". The main thing to know at this stage is the approximate total length of the proposed track. In the example it is 3,745 feet.

Consequently, there will be a need of no less than 3,745x2 = 7,490 feet of rail. 60 pound per yard rail which is a satisfactory size for tramway museum purposes and can be man-handled without too much difficulty, usually comes in 40 foot lengths. Therefore, at least 188 rails or 94 pairs will be required. On the basis of a 2 feet 6 inches centering of sleepers, the minimum number is 1,498. Both these quantities must be modified if the loop is to be added: at least some of the standard size sleepers should be displaced by longer timbers to maintain the integrity of the turnouts. Purchases of dog spikes should be seen in the vicinity of 6,000. Pairs of fishplates and fishbolts will amount to about 190 and a minimum of 760, respectively. Quite a lot of material, I think you will agree?

I am working in imperial units, not only to be readily understood colloquially, but museums will be buying second-hand or scrap materials for their use into the foreseeable future and these are of inherent imperial size even if sold by an adjusted metric standard.

Now that the basic permanent way material quantities have been ascertained, it is important to have the right tools with which to fabricate the track. These days, mainline railway construction and maintenance, though still fairly labour intensive is highly mechanised, with much sophisticated equipment. Volunteer tracklayers, however, will be limited to using the more traditional items such as, picks, shovels and bars, hammers, tongs, spanners and jacks with the concession, hopefully, of a heavy duty motor-generator for powering an electric drill. A track gauge, preferably two or three, should also be acquired or made.

I suspect all the above tools can be bought, loaned or hired from the local railway authority. Bearing in mind the obsolescence of these tools, they could be given away if your museum's credentials are good. Don't forget they will be needed again for maintenance after the line is operating.

With the "shopping list" compiled, it's time to have it priced. No doubt some prior contact has been made with the local railway authority and it is known to whom this enquiry should be directed. Some of the materials may not be available in the quantities required, but as the tracklaying project will probably be done in sections over a period of time, this should not be a cause for undue concern.

A cost will be arrived at for the materials and tools available, at which stage budgeting for the project will assume precedence. This aspect does not come within the scope of this address, but I make the point that all the foregoing remarks on the object of the museum, the liaison planning, and the material needed for the tramway track are of crucial importance to establish, if, external sources of labour and finance suddenly become available. For example, a Regional Employment Development (R.E.D.) scheme. At the A.E.T.M. we were fortunate to be able to take advantage of such funding.

Earlier I mentioned briefly the different approaches which, of necessity, have to be adopted in response to the nature of the roadbed offering for the track. I will now deal with the matter concerning the need of preparing a roadbed on other than a flat surface. Fundamentally, this is earth-moving. Like many things, the cost is proportional to the amount to be done, and a clear idea of what is involved is essential.

If an engineering surveyor exists within the museum membership, he should be encouraged to perform a ground profile or levelling survey over the route of the line. Otherwise it will be necessary to contract one. Short cuts in surveying are a false economy when earth-moving machinery has to be engaged.

The anticipated design grades and the quantity of earth to be moved has to be co-related and budgeted. As much of the route as possible should be prepared at any one time and the exact requirements for the plant operators to work to known. I emphasize these two aspects as the commercial hiring rates for bulldozers, graders, backhoes and tip trucks are high. (Graders were $40 an hour in South Australia at last count.) Hire services charge travelling time to and from the job-site, a cost component which rises sharply if less than a normal eight hour shift is done. Any on-site delays due to confusion and misunderstandings are also at the client's expense. Weekly rates are cheaper than at weekends, and provided the job-site is intelligently picketted for both alignment and levels, an average plant operator can perform his duties without further supervision.

Some of the requirements for a ground profile survey using the former model are shown.

Most fill needs compacting, but this expense can be avoided. Usually the continuous passage of the earthmoving equipment over the spoil is sufficient to pack it for the purpose of a tramway track. The natural elements of sun and rain will complete the process in reasonable time. Compacting is counter-productive if the spoil has been dumped on swampy ground. Under these circumstances it is better to leave it as long as possible to compact as well as it can, or ignore it and be reconciled to a prolonged period of slumping with the attendant need to continually level the permanent way. The latter situation prevails on the causeway section of the A.E.T.M.'s St. Kilda tramway.

There are two alternatives I can suggest to reduce or even eliminate earthmoving costs. This industry is still very competitive, with many entrepreneurs trying to break-in on the market. A local, "middle-rank" firm may welcome the opportunity to sign-post its existence at an explicitly public-oriented venue such as a tramway museum in exchange for reduced "off-peak" hiring rates. Their work could then be seen and judged by potential business clients amongst the visitors.

Royal Australian Engineer Units of either the Citizen Military Forces or regular army may exist in your neighbourhood. They undertake certain community projects free of charge where they feel there is no conflict with the commercial sector of the industry. The Tramway Museum Society of Victoria has had experience with them in this field. Generally, the R.A.E. have a long waiting list for jobs (presently two years in South Australia) and prefer to tackle all aspects of the projects (including the surveying) as a training exercise.

It is a common illusion amongst volunteers that the roadbed should be "level" prior to tracklaying. This is not necessary, and pursuing it is a waste of time and energy. The immediate requirement on a completed roadbed is a thin (3-4 in.) run of stone or quarry rubble from a tip truck. This provides a minimum bedding for the sleepers consistent with drainage, and in wet weather gives a comfortable working surface for the tracklayers.

Now it is time to consider doing the final engineering survey for the track alignment. As I said earlier it is not vital, but desirable. At the very least the curve intersection pickets should be re-established and intermediate pickets lined up along the tangents. The exact distance to the required point of curvature (tangent points) should also be measured along the tangents from the curve intersection point. This is probably as much as the layman can do, but anyone with a reasonable flair for maths. can go a step further and substitute the known values in the appropriate formulae for curve ranging and so estimate the position of the secant point for a particular curve. Provided the curve is not too long, the track can be laid to look reasonable and act appropriately. Diagram "A"

It is possible where no topographical or physical obstruction exists between the centre, tangent and secant points of a curve, to "swing-off" the radius and mark the arc of the curve with pickets in the process. However, there are limiting conditions. The"swing-off" material can rarely be handled over distances longer than 300 feet, and the precise centre of the curve must be known for this method to be effective.

There is no need for me to elaborate on the instrumental curve ranging procedures as these will be known to any engineering surveyor.

The job of physically laying the track is at hand. It should already have been decided who is the officer-in-charge of the project. Preferably he should be a "stayer" if it is a long term programme, otherwise there is a risk of it lapsing into chaos if he quits. Continuity in control will ensure ease of material stocktaking and the productive use of labour. An inspired leader will maintain the morale of the personnel engaged on the track construction when the novelty of lifting hundredweight sleepers, and the lugging of tons of rails into position begins to wear off as it will assuredly do so over a distance of a mile! The team should have at least two other people made familiar with the requirements of the project and who are capable of elementary supervision. This will relieve the burden of the work on the leader.

Assuming that the laying of the tracks in the sheds has been completed during the initial development of the museum, the requirements of the yard must now be considered. The centre line projection of the numerous tracks beyond the shed entrances should be picketted, and the linear and angular measurements of their respective intersections with each other noted. A plan of these should be plotted to scale and similar scale templates of the turnout assemblies superimposed on this plan to see where they best fit. Fouling distances to curves adjacent to shed entrances and other impediments should be noted. The optimum solution in respect of the permanent way material to be used and the ease with which it can be assembled is then ready to be translated back onto the picketed lines in the yard.

The drafting may seem frivolous, but the whole procedure can be accomplished in 24 hours and the geometry of the track clearly defined on the ground. The little extra effort here will be rewarded, for the permanent way materials can then be dumped where they will be used. There is no fun in moving awkward and heavy stores around more than once.

The turnouts should be laid first, fully bolted, spiked and aligned. I will enlarge on these activities presently. Next the yard curves should be constructed. These will almost certainly be fairly sharp, so curvature will have to be imparted to the rails by means of a Jim Crow or similar device. The approximate radii of the curve rails can be scaled from the plan, and "swung-off" on a flat piece of ground on or near the proposed curve. Wooden pegs or steel pins should be hammered-in flush with the ground at yard intervals along the line of curve for the maximum length of the rails to be curved. The rail is then moved to within proximity of this pegged curve, the Jim Crow attached to one end, and curving begun a foot or so at a time.

A word of warning here! It is certain that tramway museums will have recourse only to second-hand rail. The running surface must be checked for its wear profile. If the running surface is flat, the rail can be turned to present the unworn gauge face. If however, the running surface is sloped,

the existing gauge face must be maintained. Rail too worn should not be used as it will ruin the tramcar tyres as well as reducing essential adhesion qualities.
Diagram "B"

Preferably a rail join should not fall at a tangent point (assuming transition curves are not used) due to the thrust forces imposed there by the changing direction of a moving tramcar. So it is possible that curvature may commence at any distance along the rail.

I presume most museum members have had some experience in using a Jim Crow? After the first few applications of the clamp, the pressure which needs to be exerted to curve the rail can be estimated. There is a tendency to "over-bend" the first 6 to 10 feet of the rail for it takes that length to detect any noticable deviation in alignment. It is better to decide on curving the rail twice than subject it to varying, corrective curvature. This is a source of derailments on sharp curves. Rails for long curves should not be Jim Crow"-ed" by volunteers. Within reason, it is wiser to "spring" them.

When the rails for the curve have been Jim Crow"-ed", they can be manhandled into position, fishplated together and roughly gauged. The alignment can then be imposed, if necessary, by "springing" the rails with thick, long steel pickets driven into the ground beside them. In this position the curve should be carefully dog-spiked. On completion of this step, straight rails should be measured and cut to fit between the curves and turnouts. These rails should be fishplated and dog-spiked before the steel pickets are removed from a "sprung" curve otherwise problems will result in bridging the intervening distance.

It is likely, for reasons of safety, that yard trackage will be ballasted or sealed to rail head. This poses problems of stormwater drainage, especially since all the tracks are likely to be at a common level for the purpose of union. It would be wise to consider localised water collector traps and underground pipes at an early stage of planning.

The principles applying to the laying of yard trackage should be followed also in the construction of the main line, particularly the prior laying of turnouts. Assuming an engineering survey of some description has already been done, the measuring tape should not be used to peg the distances of successive pairs of rails. A pair of 40 feet long rails will require 16 intermediate sleepers to rest on, leaving about 15 inches of rails overhanging at each end. Sleepers should not be placed any closer to joins as most fishplates are designed to be dog-spiked to the configuration outlined.

You will notice I have consistently referred to pairs of rails. The join in the rails is the "weak link" in the track. This fact lies behind the policy of using continuous length, welded rail as much as possible in mainline railway practice to-day. Over the years, all sorts of ploys have been adopted by railway engineers to minimise this failing. My own experience and one that I'd recommend has been with matching pairs of rails on the tangents and a 50% stagger on curves. The theory behind this method doesn't concern us, but practically it facilitates the positioning of sleepers, and notably so on curves where the "creep" of the inner rail (the distance of the curve along the inner rail is shorter than along the outer rail) can be countered most easily.

The pegs denoting the ends of pairs of rail lengths, should be substantially planted in the ground, and in a straight line on tangent track. Sleepers should now be brought forward from the store by trucks,etc., and 16 dumped for each pair of rails (matching or staggered.) If the sleepers are second-hand, a certain amount of culling will be desirable to eliminate those with badly split ends, or too many dog-spike holes. Experience is the only judge for selection. It will probably be preferable to now lay them upside-down. Many sleepers are notched and this could provide an uneven bearing surface for the rails the "second-time-around". Each sleeper should have its centreline marked with paint or waterproof crayon and then roughly spaced and aligned.

A 50 feet length of 1 inch rope, knotted every 2 feet 6 inches each way from the centre to lie evenly between the "0" and "40" feet marks, should then be stretched taut between each successive group of rail pair pegs and the spacing and alignment carefully performed against the knots and painted lines,respectively.
Diagram "C"

Only just sufficient sleepers should be positioned as can readily receive their pairs of rails. Despite their weight, sleepers are in keen demand and quite frequently stolen! The rails should be placed close to, if not on, the sleepers in one move from the store, and bar-ed into the chosen alignment and gauged on the sleepers. If the fishplating and bolting is to be done in cold weather, 1/4 inch wide steel shims must be temporarily placed within each rail join during this process to allow for heat expansion in summer. It is not necessary to use shims if the temperature is above 30° C. On a six hole fishplate, the second and fifth bolt can be omitted, but all bolts must be placed on the four hole fishplate. Oil should be used copiously on fishbolts to allow them to be continually tightened after the track is commissioned.

Before commencing the drilling of holes in the sleepers for dog-spikes, the centre bar of the track gauges should be marked at the 2 feet 4½ inch (depending on the gauge!) point and kept constantly in line with the centre-line painted on the sleepers. This will maintain the alignment of the rails as dog-spiking proceeds. The left hand side rail should be selected as the "guideway". A two-speed electric drill will enable a choice to be made in using either high-speed alloy-tipped bits, or low-speed auger bits. The former are more easily re-sharpened and tempered. In both cases, the diameter should be slightly smaller than that of the dog-spike, and no less than half a dozen should be on hand to allow for bluntness or breakages.

The bit should be placed hard up against the foot of the rail and the hole drilled vertically. The dog-spikes are then hammered part-way home. The "guideway" side of the sleeper should be done first so that the gauge can be checked to see if it fits snugly before drilling for the other rail. "Gauge widening" is necessary only on sharp curves. The dog-spikes for the other rail are then fully driven home together with those on the "guideway" side, before proceeding to the next sleeper. There is a technique to driving dog-spikes which can only be acquired with practice. A dogging hammer is made to drive each spike across the rail and this should be borne in mind when trying to learn the art! There will be plenty of opportunities to do so as the work proceeds.
Diagram "D"

The final process of the track construction will be its levelling or grading. This can be carried out in conjunction with the use of survey instruments called a level and a staff, or alternatively, with a group of three "T"-shaped bars called boning rods. The combined use of both means is recommended. A level and staff are not difficult to use, but undetectable mistakes are easily made so they could produce a travesty in the hands of novices. A diagram showing the use of boning rods is appended.
Diagram "G"

If a level and staff is not a practical facility, the following course should be adopted for grading the track. It will not produce as good a result, but will still look quite professional in appearance and be functional.

Look along the left hand side rail at eye level from the point of commencement of tracklaying. Take note of the next highest and lowest points on the head of the rail, and have them marked with paint. Move to the next highest point and continue observing and painting all the high and low points to the end of the line. Continuous design grades must now be determined. These should be as long as possible, consistent with the economic provision of ballast. A lift of one foot in the track should be regarded as a maximum. The high and/or low points fulfilling these two conditions should be selected as the design changes in grade. A stout, flat-topped peg should be placed against the rail opposite these selected points and driven into the ground to conform in height with the head of the rail.

The target boning rod should be placed to stand vertically on the peg away from the sun or glare, and the sighter rod similarly positioned on the peg at the other end of the selected design grade. It takes four men to bone, one observer, one to hold each of the target and sighter rods, and one to move the traveller rod. The travellor rod operates between the other two, and sights should be taken on the running surface or head of the left hand side rail every 10 feet or so. It is axiomatic that all of these intermediate sights will be taken of a point of rail which is too low and therefore has to be raised. This should be done with the track jacks as the traveller is moved along, and a small amount of ballast to hold and maintain the correct height, beaten under the nearest sleeper with a pick. A straight-edge and spirit level lying between the rails will enable the right hand side rail to be adjusted for correct height simultaneously.

If a curve is involved, the boning should be performed on the inner rail, regardless of previous instructions. A cant board (a straight edge with an underside "laddered" in 1/4 inch steps) should be employed to introduce the calculated cant or super-elevation to the outer rail. Cant is the product of a number of linear and kinetic factors which can be mathematically reduced to tangible ordinates capable of being applied to the track during construction. Cant assists a moving tramcar to negotiate a curve and also prevents gauge and alignment distortion to the track. The calculations <u>should</u> take into consideration the introduction of transition curves both before and after the main, circular curve, but for tramway purposes the required cant can be obtained by substituting known values in the following simple formula.
Diagram "E", Diagram "F".

I should also mention that tramway practice does not require level or horizontal sections of track between an up and a down grade, and vertical curves can be ignored provided the change of grade is not excessive. Volunteers will find that the track will take up a satisfactory vertical profile of its own when lifted and packed.

When the track between two outer boning rods has been graded by observation, it is then necessary to pack all the sleepers on that section properly. This may require the addition of substantial quantities of ballast, and only then should it be ordered for delivery by tip truck. If the track is accessible to road vehicles, the ballast can be poured onto the track directly without any harm being done. Failing this, a front end loader or wheel barrows will have to be used for conveying it from a strategically placed pile. The aim should be to reduce the amount of manual labour.

Ballast should be hard-packed beneath the sleeper for at least one foot either side of the rails, moderately packed at the ends, and lightly packed in the centre. This prevents sleeper "bowing" as the track "beds-in" under load. A final check on the evenness of the grade in the section of track just packed should be made with the boning rods before moving on. The level pegs can be reclaimed for use on the next section.

If, on completion of the lifting and packing, the grade profile appears good, it may prove worthwhile to set permanent steel level pins to assist in preserving it. These pins must be installed before any load is placed on the track. They should be concreted into the subgrade beyond the bearing surface of the track, and the top of the pin must be a constant depth (15 inches is suggested) square below the level of the "guideway" or inner rail on curves. The accompanying diagram indicates how they can be used for maintenance purposes.
Diagram "H"

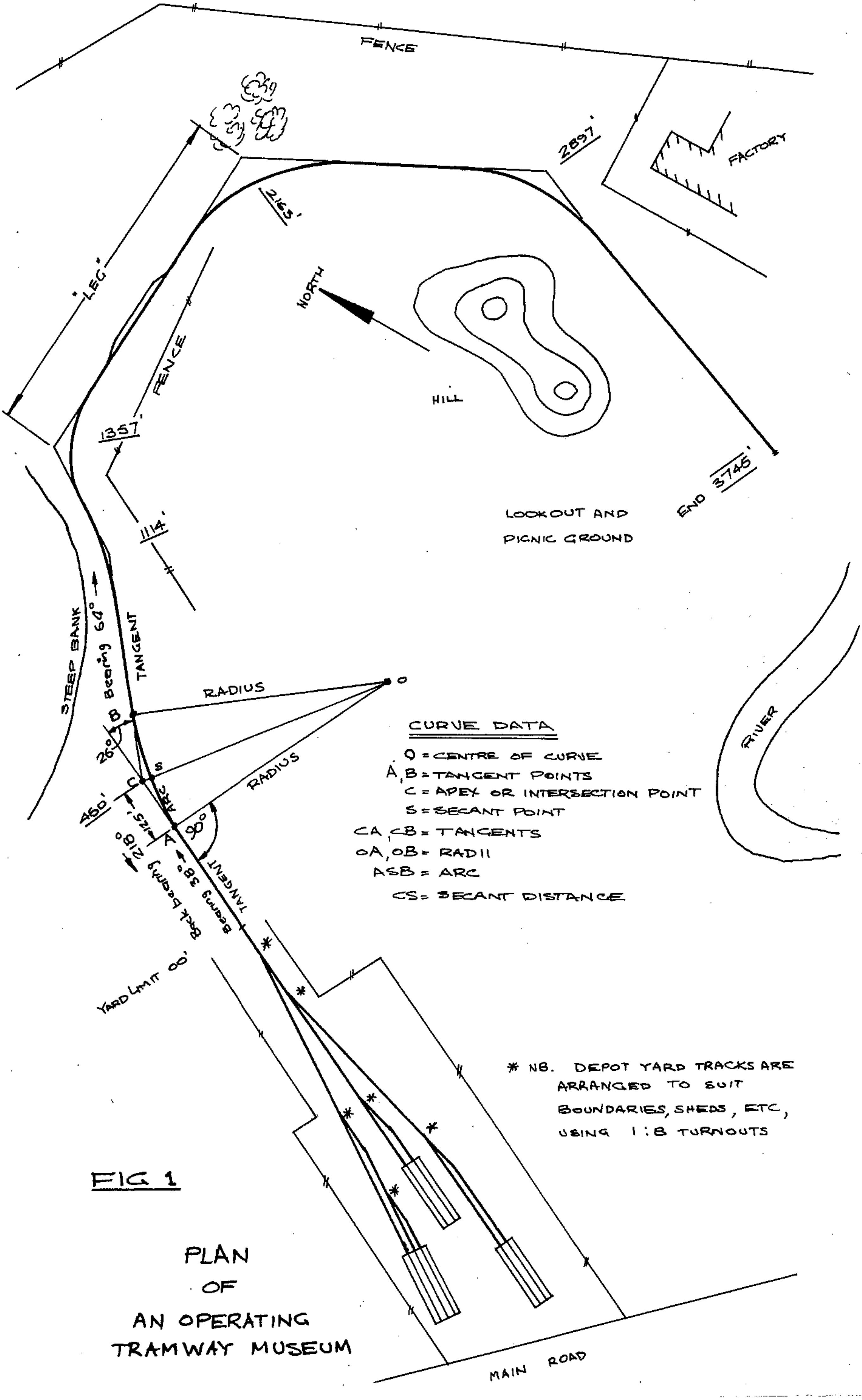
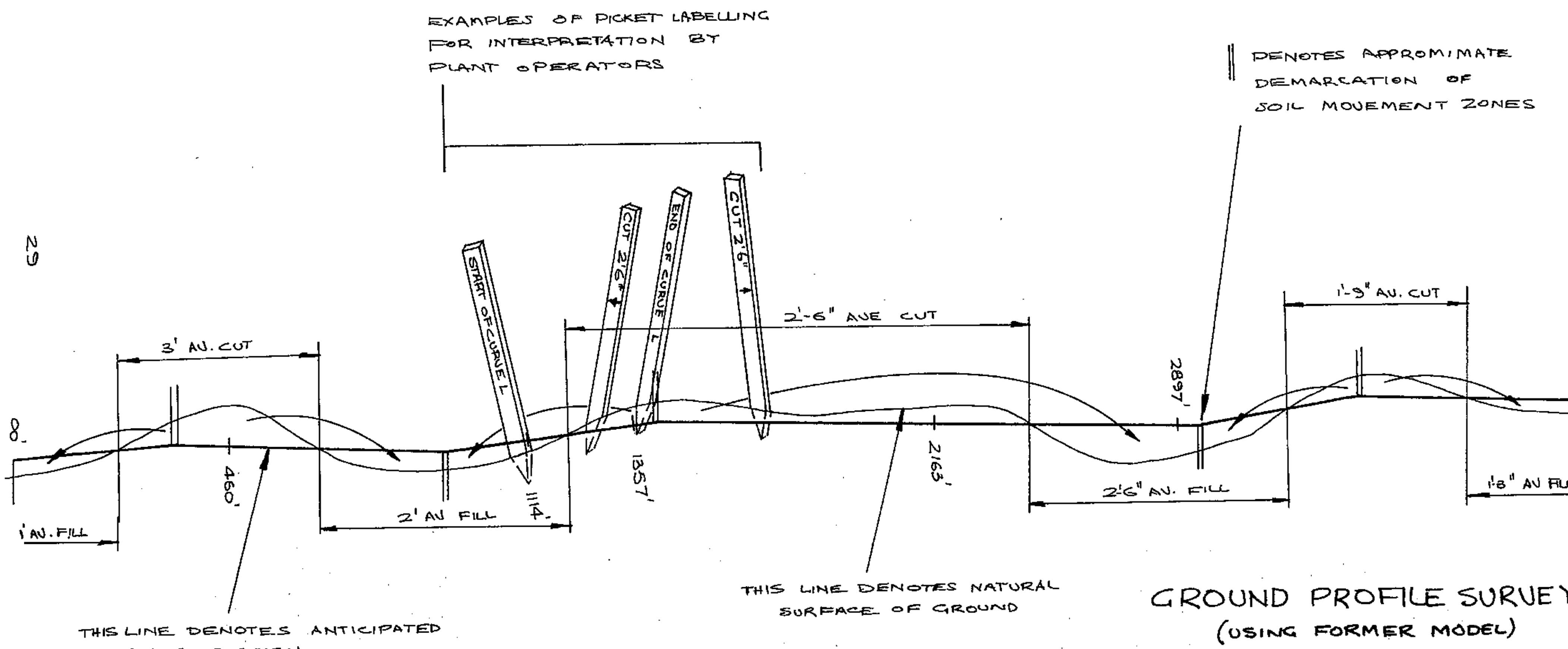


FIG 1

PLAN
OF
AN OPERATING
TRAMWAY MUSEUM



GROUND PROFILE SURVEY
(USING FORMER MODEL)
MAIN LINE ONLY

FIG 2

$$OC = \frac{\text{TANGENT}}{\text{SIN } \frac{1}{2} \text{ INTERSECTION ANGLE}}$$

$$\text{RADIUS} = \frac{\text{TANGENT x SIN } \frac{1}{2} \text{ SUPPLEMENT INTERSECTION ANGLE}}{\text{SIN } \frac{1}{2} \text{ INTERSECTION ANGLE}}$$

SECANT DISTANCE = OC - RADIUS

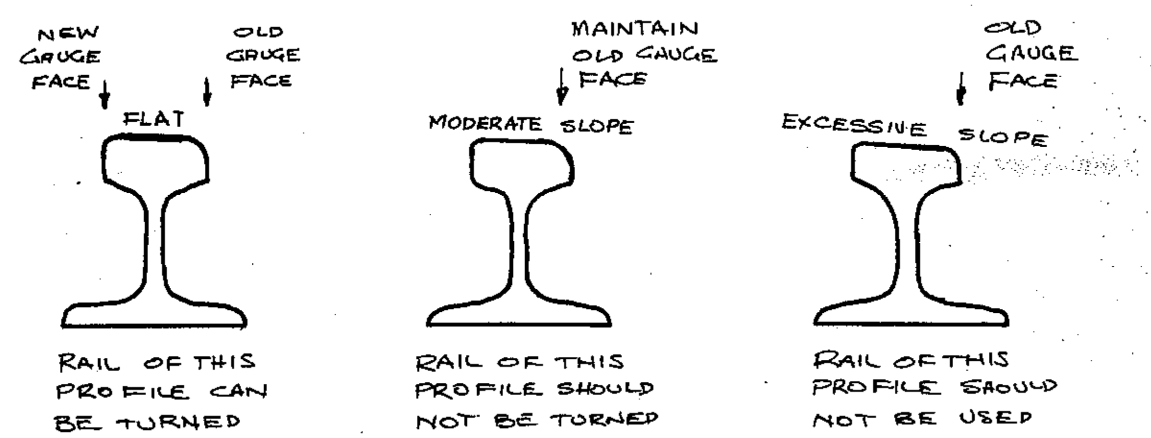
<u>Example</u>: From diagram 1

$$OC = \frac{125}{\text{SIN } 13^\circ} = \frac{125}{.22495} = 555.67$$

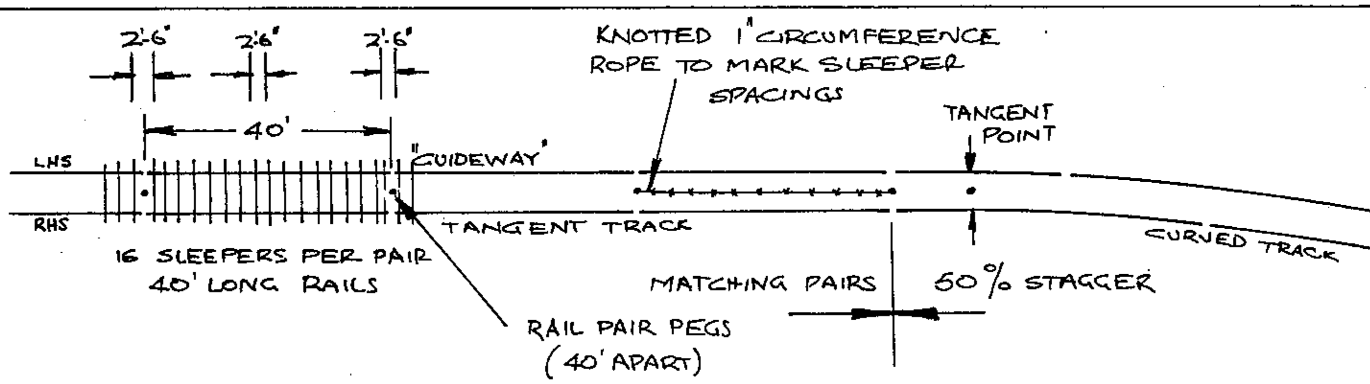
$$\text{RADIUS} = \frac{125 \text{ x Sin } 77^\circ}{\text{SIN } 13^\circ} = \frac{125 \text{ x } .97437}{.22495} = 541.43$$

SECANT DISTANCE = 555.67 - 541.43 = 14.24'

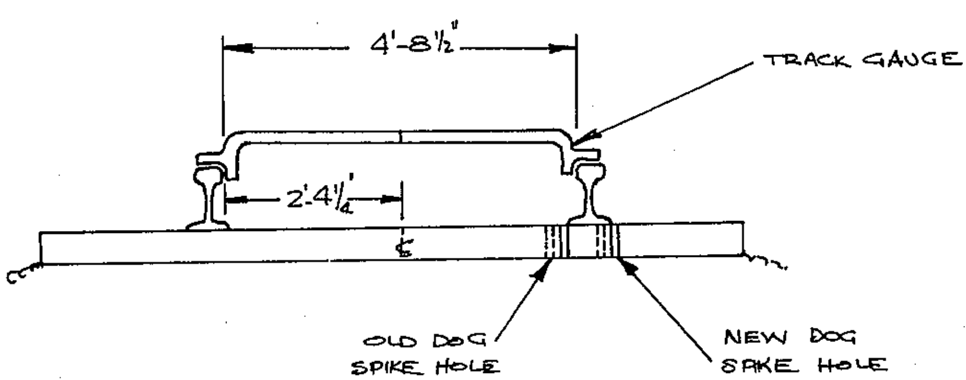
A



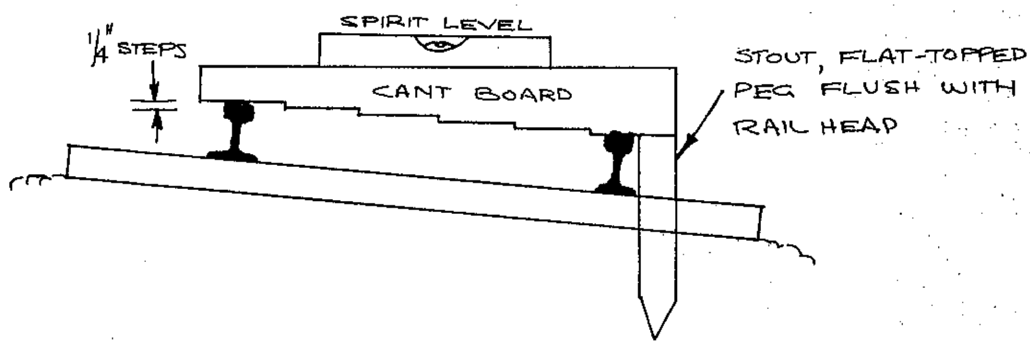
B



C



D



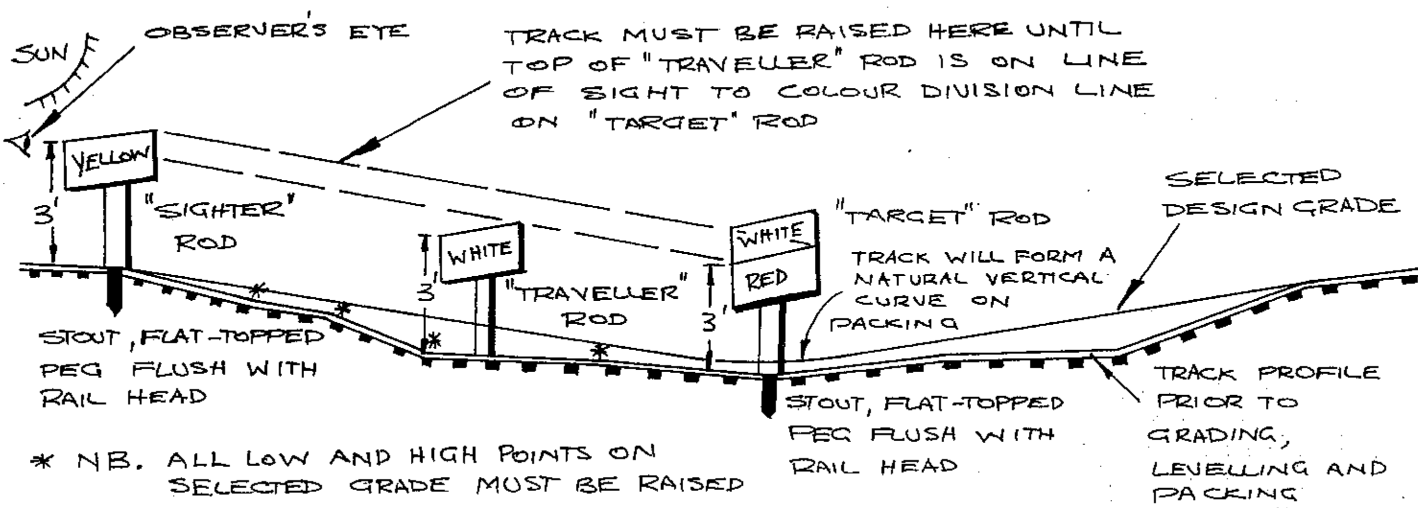
E

V= AVERAGE SPEED FOR CURVE IN M.P.H.

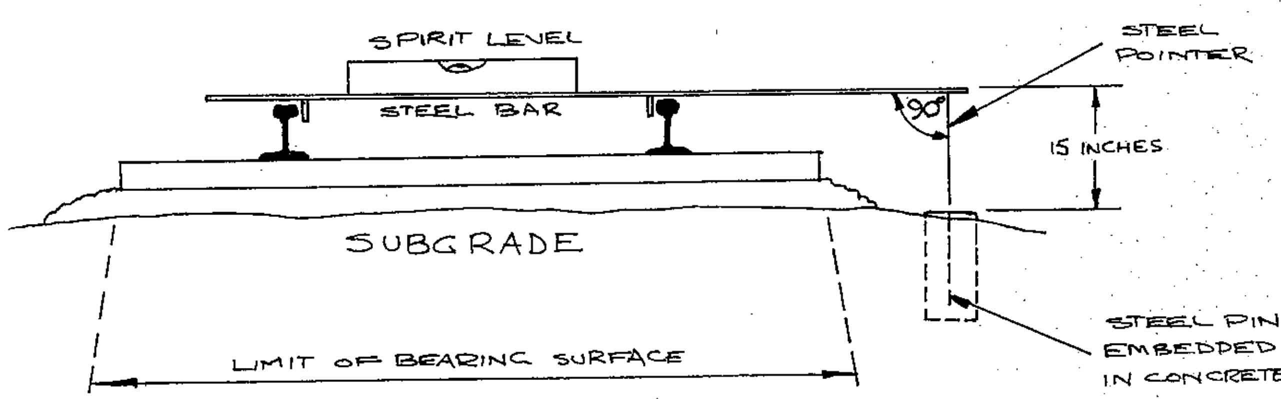
R= RADIUS OF CURVE IN FEET

CANT IN INCHES = $\frac{V}{R} \times 3.77$ (4' 8½" GAUGE ONLY)

F



G



H