STRINGLINING OF RAILROAD CURVES

COMMITTEE REPORT

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In this age of automatic tampers, computers, geometry cars, and, of course, reduced forces, why bother teaching the traditional methods of stringlining? The answer to that question is that the traditional methods of stringlining will allow the practitioner to rapidly field determine curvature and, if necessary, line track with low tech hardware.

Railroad track is a dynamic structure, and there are many causes of its movement from design alignment to one of irregular alignment, particularly on curves. Train operations impart forces to the track structure which over time tend to change the alignment. This was recognized early by our predecessors who discovered that as speeds increased, the alignment entering and leaving simple curves became distorted, which in turn lead to the development of transition curves between the tangents and simple curves and spirals.

However, even with perfectly designed curves with the correct superelevation and spiral length for the associated curvature and track speed, lateral forces will still occur as not every train will be operating at design speed. Running traffic at an unbalanced condition is a compensation for this, but lateral forces will still be imparted to the track related to directional tonnage, grades, and current of traffic operation.

Therefore, alignment should be expected to change or deteriorate as time goes by through normal operations eventually requiring surfacing and lining. Compounding the above, there exists locations not blessed with perfectly designed or constructed subgrades, which for various reasons, poor original location, poorly constructed fill, slides or high water, the alignment changes.

Another type of track instability relates to thermal expansion and contraction, primarily the dreaded sun-kink, which can make the alignment most irregular, possibly leading to catastrophic results. Less dramatic changes in alignment will occur also, as I am sure most of you have seen curves gradually shift in and out during the different seasons, especially where insufficient ballast exists.

Another cause of irregular curve alignment, or at least alignment different from what was originally designed, is previous lining. Years of smoothing and surfacing without staking will result in a curve that while perhaps not particularly bad looking or poor riding, might be off alignment. Likewise, normal maintenance operations, such as tie gangs, might shift the alignment, especially without staking curves when surfacing behind.

Deferred maintenance is included as a catch-all phrase, to remind us that railway track without the appropriate maintenance cycles for its particular territory, will deteriorate, alignment being only one of a number of interrelated characteristics. Obviously, poor tie conditions or mud holes can contribute to alignment problems if not corrected.

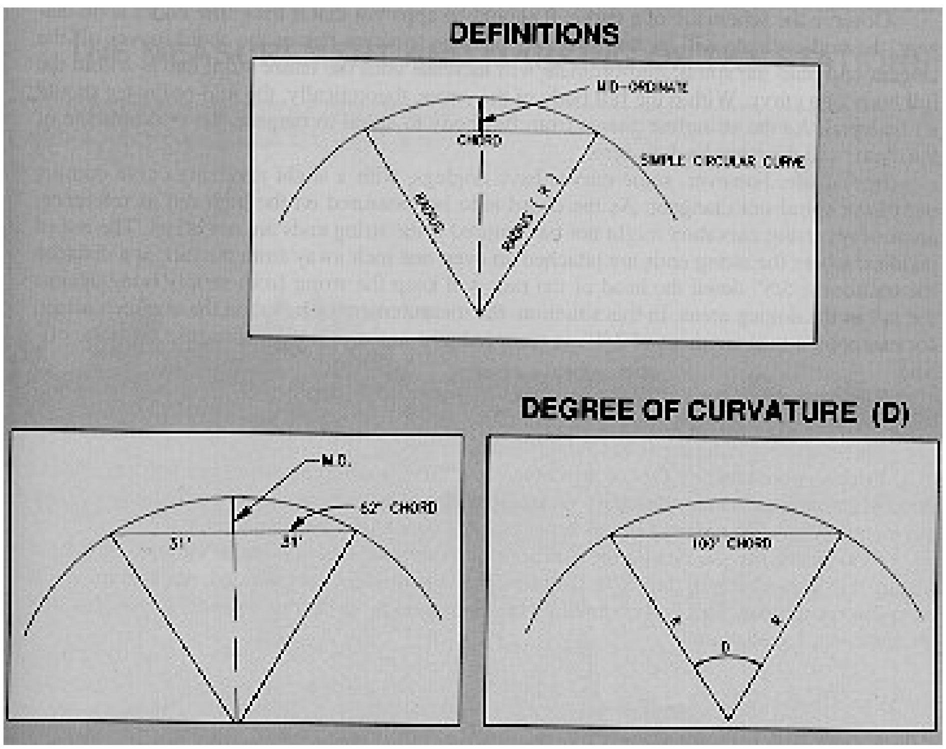
Irregular alignment affects our customers directly by reducing ride quality and schedules. Poor alignment can cause damaged lading and for passengers an uncomfortable ride. A slow order, while one corrective solution, would increase transit time eventually resulting in loss of business.

Furthermore, poor alignment affects us internally by increasing the pressure on our maintenance budget through premature curve wear, abnormal tie wear and accelerated deterioration of surface and line. Once the track is out of line, it won't get better by itself, and maintenance dollars better spent elsewhere must be diverted to correct the situation.

In order to stringline, it is useful to be familiar with curve geometry, although the beauty of stringlining is that it can be performed without a thorough knowledge of geometry or civil engineering.

By definition, curvature, that is the degree of curvature, is the angle in degrees subtended by a 100 toot chord. This is simply an arbitrary label, as other ways of defining curvature exist, such as by radius. How can curvature be measured in the field without a survey'? After all, it would be most impossible to measure the radius of a curve in the field, unless the curve was super sharp.

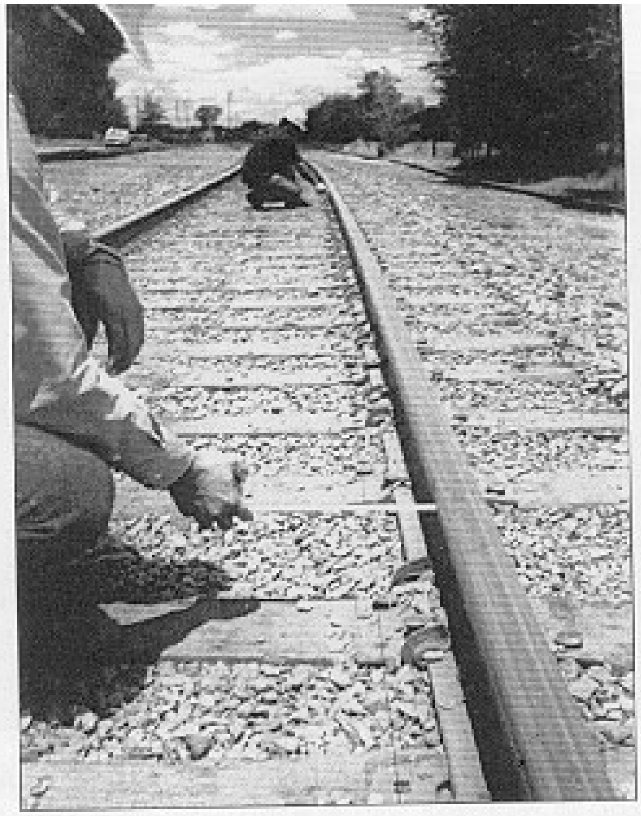
There is a property of the curve called the mid-ordinate which is the distance from the midpoint of the chord to the midpoint of the arc subtended by that same chord (By calculation, it can be shown that the mid-ordinate equals curvature squared divided by eight times the radius, but this still leaves the guy in the field saying, "so what?")



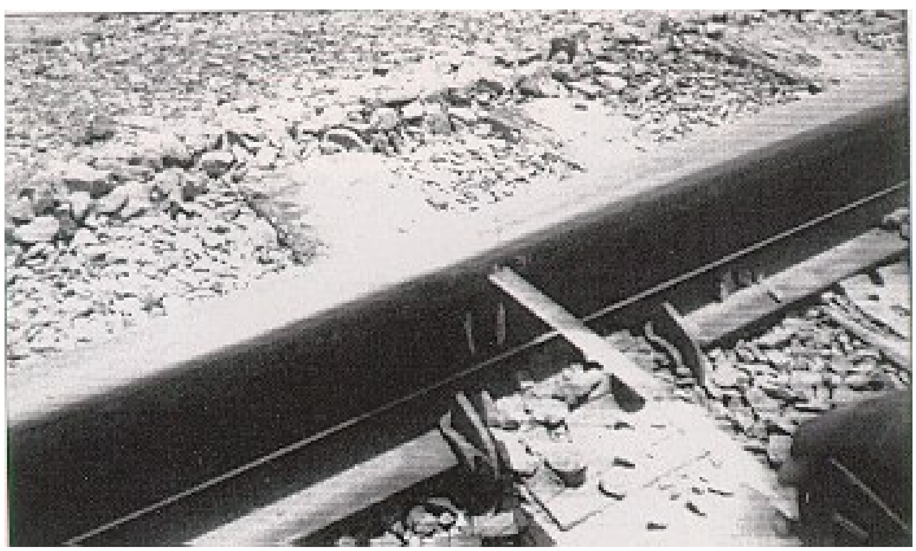
Well, if a 62-foot chord is used instead of the 100-foot chord, it just so happens that the mid-ordinate measured in inches is approximately equal to the curvature in degrees. In other words, if the mid-ordinate is three inches, the curvature is three degrees and so forth. If you want to check this out for yourself, refer to the right triangle formed by the radius (hypotenuse), the half-chord (31') and the radius minus the mid-ordinate, which forms the adjacent side. Remembering from your geometry that the adjacent and opposite sides of a right triangle squared and added to each other equal the hypotenuse squared. In the case of a one-degree curve with a radius of 5730', the mid-ordinate works out to be 1.006", close enough for railroad work.

THE MEASUREMENT AND MARKING OF THE STATIONS

So now we have a quick and easy way to field check curvature. All that is needed is something to form a 62-foot chord, something to measure the mid-ordinate, and a way to fasten both ends of that chord, such as a couple of stout lads.



THE MEASUREMENT OF THE MID-ORDINATE



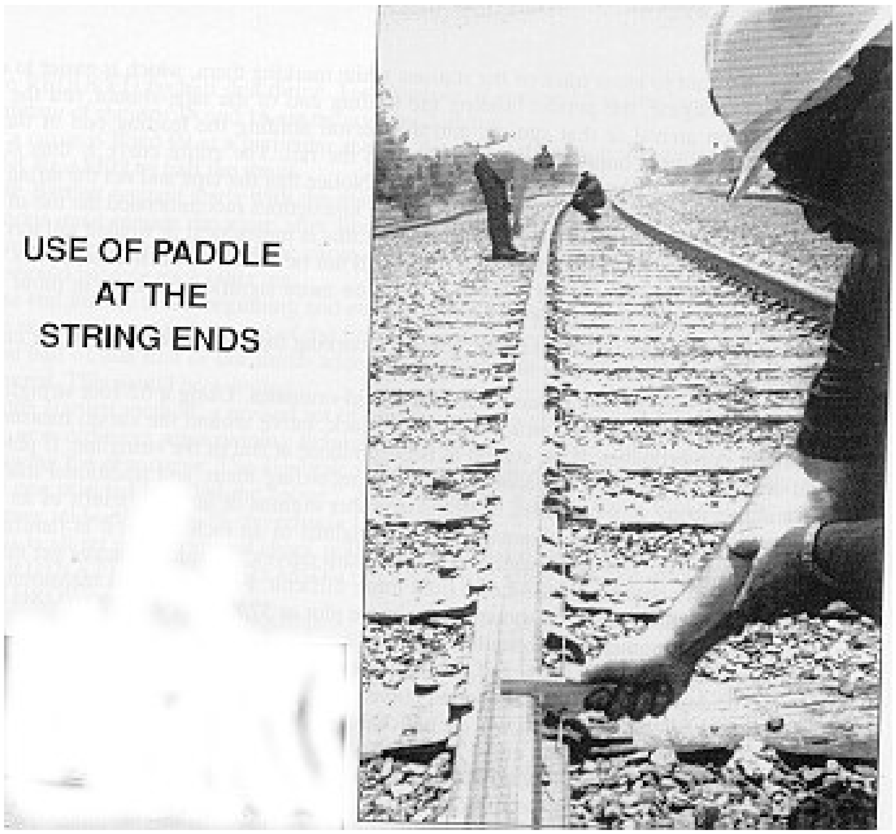
Let's review our shopping list:

- A steel tape, in order to measure the half chords, which will be the stations.
- Some sort of marking device, like kiel or paintstick.
- A string, preferably a chord with properties unlike that of a rubber band--it should remain at 62' under tension.

- Something or someone to clamp the string ends.

- A tape measure, and someone to hold it and take notes.

That's it. It's fairly low tech.

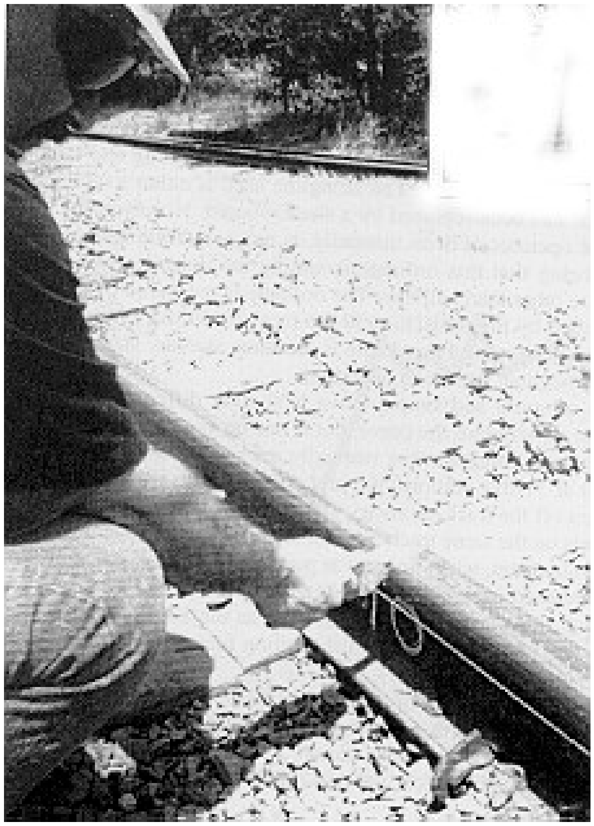


Paddles can be used to which the string ends are affixed, for reasons which will become apparent shortly.

Observe the schematic of a curve. It should be apparent that if the entire chord is on tangent, the mid-ordinate will be zero. It should also be apparent that as the chord moves off the tangent and onto the spiral, mid-ordinate will increase until the entire stringline is within the full body of' a curve. Within the full body of the curve, theoretically, the mid-ordinates should all be equal. As the stringline passes from full body to spiral to tangent, the mid-ordinate of the chord will decrease back to zero.

In real life, however, some curves have doglegs, with a slight reversing curve coming out of the spiral onto tangent. As the chord is to be measured on the high rail as reference, areas of reversing curvature might not be captured if the string ends are not offset. The use of paddles, where the string ends are attached an even one inch away from the rail, at a distance the traditional 5/8" down the head of the rail, will keep the string from simply lying against the rail in the dogleg areas. In this situation, the measurement of less than the one inch offset, for example, a measurement of 3/4", ii recorded as a negative 1/4" (subtracted from the offset).

The most direct way to illustrate what has been said is graphically. Here are the recommended steps in field measurement of curvature:



The necessary equipment has already been reviewed.

Prior to commencing this or any other operation, a comprehensive job briefing should be held in order to ensure the safety of all the participants, which should particularly address protection from train traffic, and any other hazards which may be encountered.

Next, mark the stations on the rail, starting with your first station far enough outside or ahead of the beginning of the curve to ensure that any doglegs are included, and that the point of spiral is captured. That is recommended to be around three or four stations. Remember, the stations ale 31 feet apart.

In order not to loose track of the stations while marking them, which is easier to do than you might imagine, the person holding the trailing end of the tape should yell the station number upon arrival at that station, and the person holding the leading end of the string should yell the next number as it is marked on the rail. The entire curve is thus stationed ahead of the measurement of the mid-ordinates. Notice that the tape and not the string is used to mark the stations. In earlier years, stringlining instructions recommended the use of the rail joints as the stations (rather than measuring), but this is impractical in welded rail territory. If joints are used, keep in mind that the stations will not be at 31', so the mid-ordinates will not relate exactly to the degree of curvature. Of even more significance, keep in mind that the rails sure need to be of uniform length.

As at the beginning of the curve, continue marking the stations well out of the curve and onto tangent.

The next step is the measurement of the mid-ordinates. Using a 62-foot stringline, held tight so as to eliminate inaccuracy caused by slack, move around the curve, measuring and recording mid-ordinates at the station in between those at end of the stringline. If plotting the mid-ordinates, obviously someone needs to be recording them, and traditional instructions recommend using mid-ordinates recorded as either eighths of an inch, tenths of an inch, or hundredths of a foot. The advantage of using eighths of an inch is that it is familiar to the average trackman. The disadvantage is that in sharp curves, the mid-ordinates get into multiple inches and conversion becomes a little more difficult. For example, a measurement of 4-5/8ths mid-ordinate would be shown on the curve plot as 37/8ths, or simply 37.

After measurements are complete, the data can be plotted as a mid-ordinate plot, where the approximate points of spiral and full body, points of simple curve and approximate curvature can be derived. Points of compound curves, if applicable, are likewise accessible, as are areas of poor alignment, which will be noticeable. It is important to reference on your notes those stations or areas of the curve which may restrict lining, such as open deck bridges, through trusses, road crossings, turnouts, platforms and signals.

If all this looks familiar to those of you experienced with automatic lining and tamping equipment, it is because the principles are similar. The stringline used is either a wire, laser, or light, and the guy with the tape has been replaced by a shadowboard. However, the number plotted by the machine or the operator, if done manually, is not a mid-ordinate, but simply an ordinate, the difference being that this ordinate is simply the distance between the chord and the arc at some distance other than halfway. The ordinate is measured by the shadowboard, and the chord is described by the projector and the receiver. In theory, this should make no difference as long as the location of the ordinate is the same at every station and the chord length remains the same throughout the entire operation.

Interpretation of the points of spiral and simple curve is slightly different. Obviously, these machines have the ability to rapidly plot the curve, but if one or three people were willing to spend the time and effort stringlining a curve manually, measuring the mid-ordinates every few inches rather than just at 31-foot stations, the plot would be just as accurate. Such an example is the curve plot taken off the track geometry car, where the chord can be as short as the distance between the wheels on the same truck set, and the measurement continuous.

In the days before automatic tampers, when lining was performed by hand, the mid-ordinates derived by stringlining were used in various methods to arithmetically line curves to a "best fit" condition, with minimal throws. These methods, such as the Bracket and Bartlett methods, are almost an art, trial and error systems, and the limiting factor was the size of the acceptable throw to attain the revised mid-ordinates.

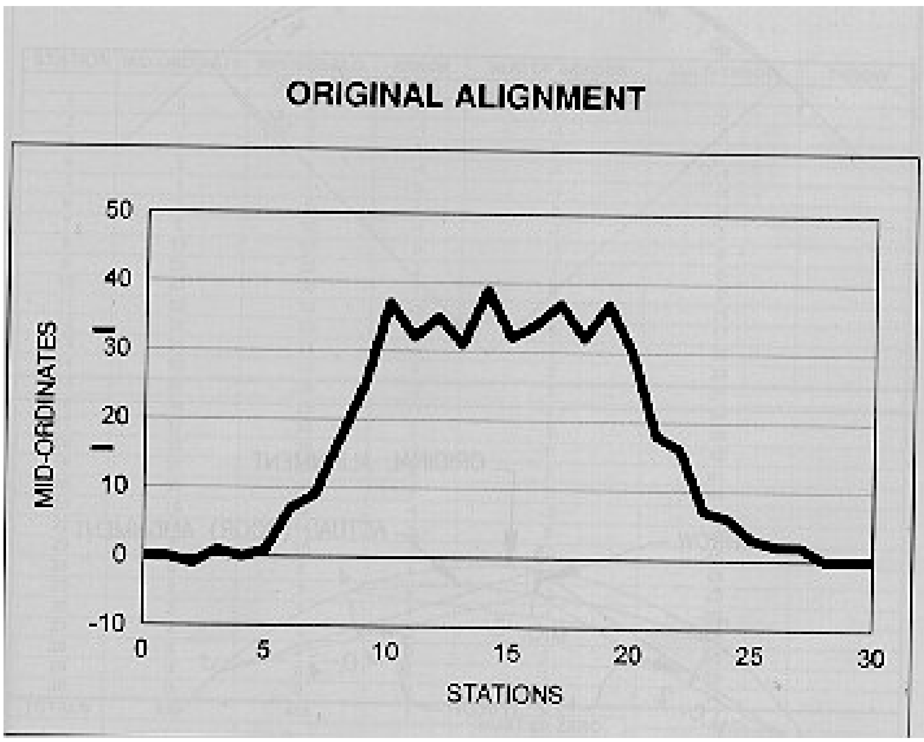
The systems are based on the following fundamental principles:

> Lining a curve out defines a positive throw; lining a curve in defines a negative throw; throw is the distance the curve is moved at a particular station.
>
> If a curve is lined OUT at a particular station, the mid-ordinates at the stations adjacent to it are REDUCED by half that throw. For example, if station 15 is lined out 4 inches, the mid-ordinate of stations 14 and 16 are reduced by 2 inches.
>
> If a curve is lined IN at a particular station, the mid-ordinates at the stations adjacent to it are INCREASED by half the throw.

The Bartlett method starts with the assumption that the sum of the mid-ordinates of all the stations must remain the same after lining. This should be instinctive assuming that no rail is to be added or taken out of the curve, and for a best fit with what is on the ground, the throws should balance each other out.

The end throws at the beginning and ending stations must be zero. If this doesn't occur, then the station immediately ahead of the first one or immediately following the last one will have one half of that first or last throw added or subtracted to its mid-ordinate, if one was to be measured. This would be a dogleg.

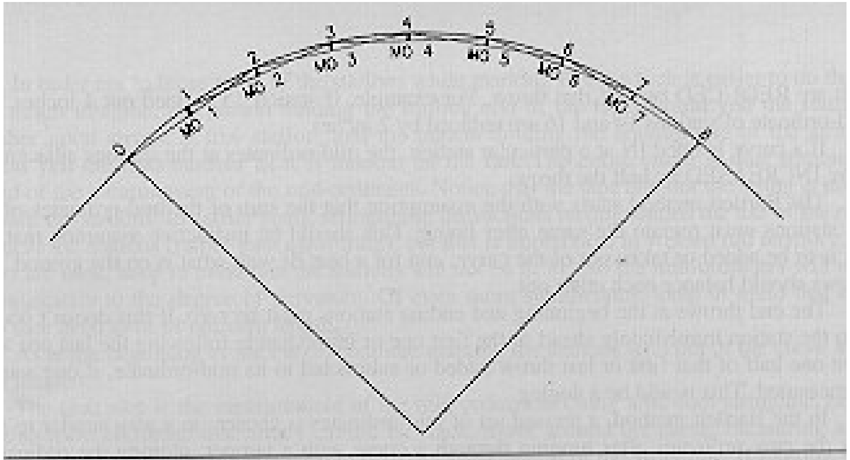
In the Bartlett method, a revised set of mid-ordinates is chosen, in a way similar to setting the new ordinates after running through a curve with a tamper, plotting the ordinates, then drawing the new curve. The algebraic difference between the original mid-ordinate and the new one selected is called the "error." As an example, if the original mid-ordinate is 17 and the new mid-ordinate is 23, the error is 17 - 23 or -6.



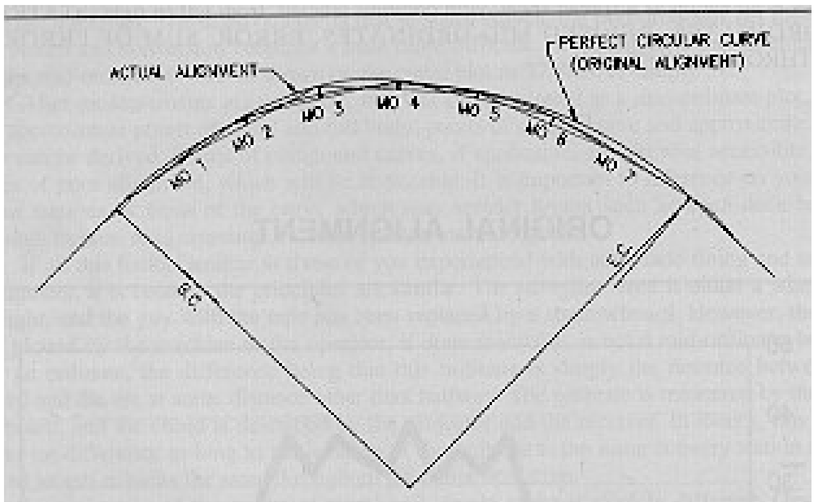
This is all set up as a spread sheet, with columns labeled, from left to right, STATION, MID-ORDINATES, REVISED MID-ORDINATES, ERROR, SUM OF ERRORS, HALF-THROW, and THROW.

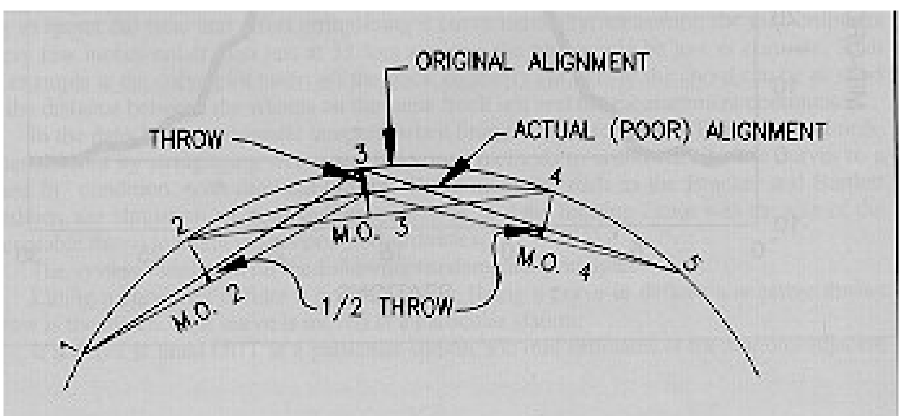
Two ways to check your progress are as follows. Add the original and revised mid-ordinates. If the sums are not equal, revise the revised mid-ordinates again in order to make it so. Also, the sum of the errors should be zero.

The column labeled "sum of errors" will have as its entry a running total of the errors up to that station. In other words, if the error at station 1 is 0, station 2 is -1, and station 3 is 0, the sum of error entry at station 3 should be 0 + (-1) + 0 or a -1. As said in the preceding paragraph, the final entry in the "sum of errors" column should be zero.



FOR A SIMPLE CURVE (USING THE SAME CHORD LENGTH), THE MID-ORDINATES ARE EQUAL





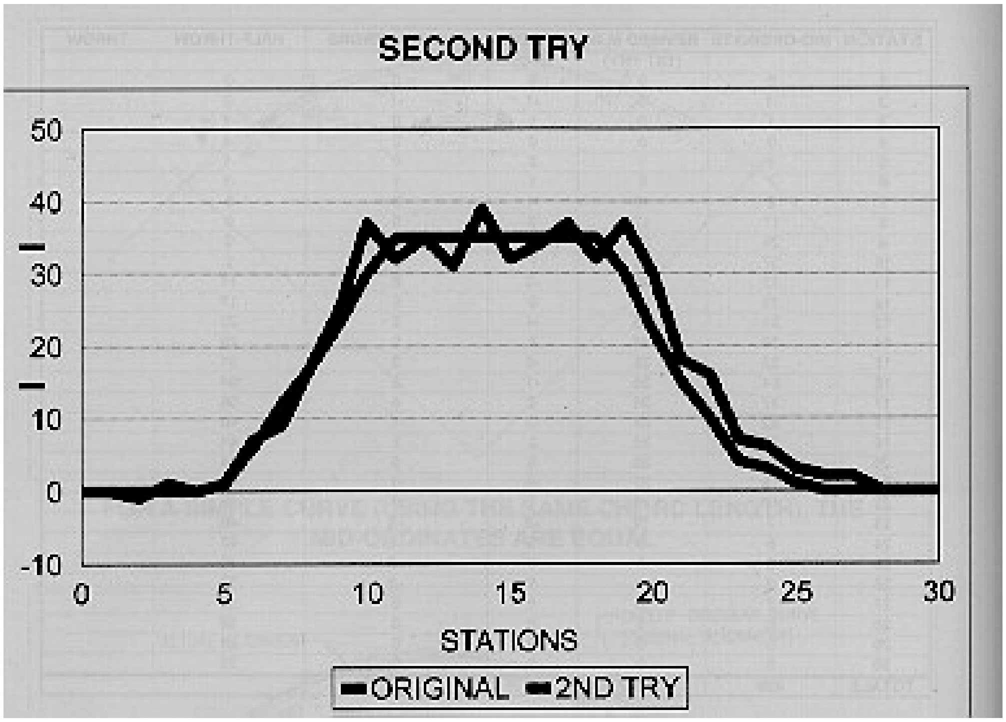
The column labeled "half throw" is the algebraic sum of the errors up to the preceding station and the half-throw of the preceding station. This takes into account the relationship between the errors and the throws. As example, if the sum of errors at station 25 is -3, and the half-throw at station 25 is 40, the half-throw at station 26 is now -3 + 40, or 37.

STATION	MID-ORDINATE	REVISED M.O.	ERROR	SUM OF ERRORS	HALF-THROW	THROW
		(1ST TRY)	(B-C)			
1	0	0	0	0	0	
2	-1	0	-1	-1	0	
3	1	0	1	0	-1	
4	0	0	0	0	-1	
5	1	1	0	0	-1	
6	7	6	1	1	-1	
7	9	10	-1	0	0	
8	17	17	0	0	0	
9	25	23	2	2	0	
10	37	30	7	9	2	
11	32	35	-3	6	11	
12	35	35	0	6	17	
13	31	35	-4	2	23	
14	39	35	4	6	25	
15	32	35	-3	3	31	
16	34	35	-1	2	34	
17	37	35	2	4	38	
18	32	35	-3	1	40	
19	37	35	2	3	41	
20	30	30	0	3	44	
21	18	22	-4	-1	47	
22	16	15	1	0	48	
23	7	10	-3	-3	46	
24	6	6	0	-3	43	
25	3	3	0	-3	40	
26	2	1	1	-2	37	
27	2	0	2	0	35	
28	0	0	0	0	35	
29	0	0	0	0	35	
30	0	0	0	0	35	
TOTALS	489	489	0			

STATION	MID-ORDINATE	REVISED M.O.	ERROR	SUM OF ERRORS	HALF-THROW	THROW
		(2ND TRY)	(B-C)			
1	0	0	0	0	0	
2	-1	0	-1	-1	0	
3	1	0	1	0	-1	
4	0	1	-1	-1	-1	
5	1	1	0	-1	-1	
6	7	6	1	0	-1	
7	9	10	-1	-1	0	
8	17	17	0	-1	0	
9	25	23	2	1	0	
10	37	30	7	8	2	
11	32	35	-3	5	11	
12	35	35	0	5	17	
13	31	35	-4	1	23	
14	39	35	4	5	25	
15	32	35	-3	2	31	
16	34	35	-1	1	34	
17	37	35	2	3	38	
18	32	35	-3	0	40	
19	37	35	2	2	41	
20	30	30	0	2	44	
21	18	22	-4	-2	47	
22	16	14	2	0	48	
23	7	10	-3	-3	46	
24	6	5	1	-2	43	
25	3	3	0	-2	40	
26	2	1	1	-1	37	
27	2	0	2	1	35	
28	0	0	0	1	35	
29	0	0	0	1	35	
30	0	0	0	1	35	
TOTALS	489	488	1			

THESE AREN'T EQUAL, TRY AGAIN!

MUST BE ZERO. TRY AGAIN!



STATION	MID-ORDINATE	REVISED M.O. (2ND TRY)	ERROR (B-C)	SUM OF ERRORS	HALF-THROW	THROW
1	0	0	0	0	0	
2	-1	0	-1	-1	0	
3	1	0	1	0	-1	
4	0	1	-1	-1	-1	
5	1	1	0	-1	-1	
6	7	6	1	0	-1	
7	9	10	-1	-1	0	
8	17	17	0	-1	0	
9	25	23	2	1	0	
10	37	30	7	8	2	
11	32	35	-3	5	11	
12	35	35	0	5	17	
13	31	35	-4	1	23	
14	39	35	4	5	25	
15	32	35	-3	2	31	
16	34	35	-1	1	34	
17	37	35	2	3	38	
18	32	35	-3	0	40	
19	37	35	2	2	41	
20	30	30	0	2	44	
21	18	22	-4	-2	47	
22	16	14	2	0	48	
23	7	10	-3	-3	48	
24	6	6	1	-2	43	
25	3	3	0	-2	40	
26	2	1	1	-1	37	
27	2	0	2	1	35	
28	0	0	0	1	35	
29	0	0	0	1	35	
30	0	0	0	1	35	
TOTALS	439	488	1	MUST BE ZERO. TRY AGAIN!		
	THESE AREN'T EQUAL. TRY AGAIN!					

If the final half-throw is not zero, another try must be made. There is no sense in calculating the throw, which is double the half-throw, if the operation must be performed again. The recommended way to revise the revised mid-ordinates is to select two stations, the same number of stations apart as the remaining half-throw. Example, if the remaining half-throw at the last station is 10, select two stations 10 stations apart, such as 5 and 15. If the remaining half-throw is positive, reduce the revised mid-ordinate at the higher station number and increase the revised mid-ordinate at the lower station by the same amount. If the remaining half-throw is negative, increase the revised mid-ordinate at the higher station and subtract the same amount to the station with the lower number. If there aren't enough stations in the curve to use one pair, either use two pairs of stations or change the revised mid-ordinates by more than one. As you can see by the following examples, when the final sum of errors is off by only small numbers, the pair of stations to be revised again might only be adjacent.

If the mid-ordinates describe eighths on an inch, then the largest throw in this example, 38, or 38/8", equals a throw of 4-3/4".

It should be obvious from the example that this system lends itself readily to the personal computer.

After an agreeable solution is found, stakes are set at the stations according to the new mid-ordinates chosen, and the manual lining takes place. Undoubtedly it is for this reason, as well as for the fact that automatic tampers with curve lining programs do these types of calculations quickly, that almost all the respondents on this committee stated that the major value of stringlining these days is for the rapid determination of curvature in the field, with out the expense of a survey, when other methods, such as plotting with a tamper or geometry car, are not readily available. This could be of critical importance in derailment investigations and does not afford a way to line track when no references or surveyors are available. An example of this would be during derailment restoration where the panels could be lined according to the stringlining prior to dumping ballast.

It cannot be stressed enough that when lining track keep in mind your organization's instructions on disturbed track and consider clearances, where a best fit solution to a curve lining problem could impair the clearance on an adjacent track, signal or other structure.

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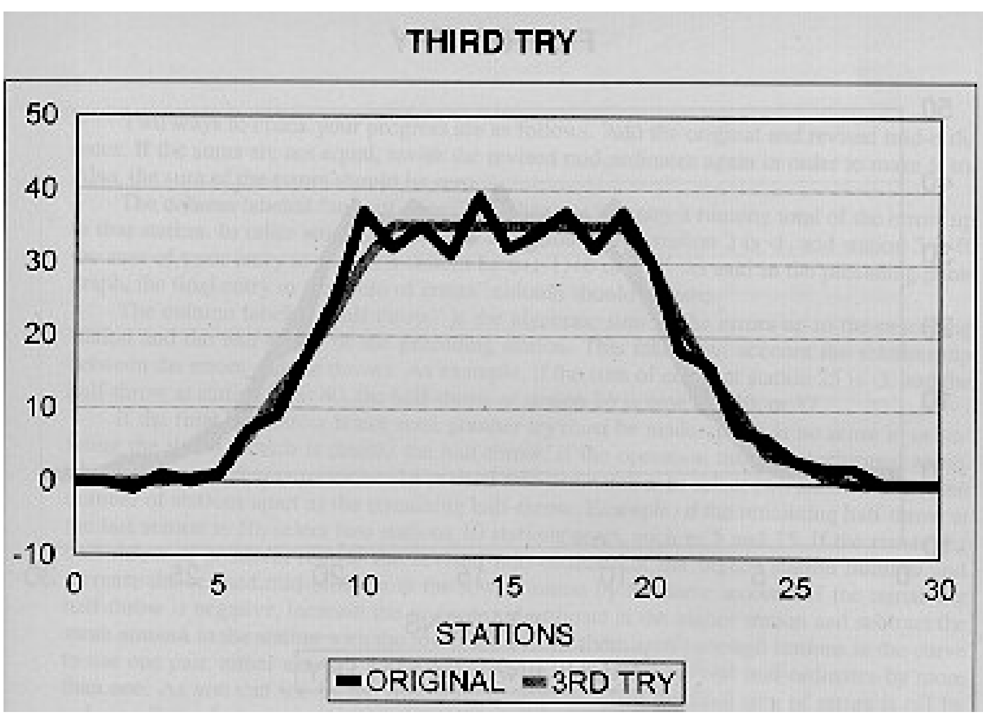
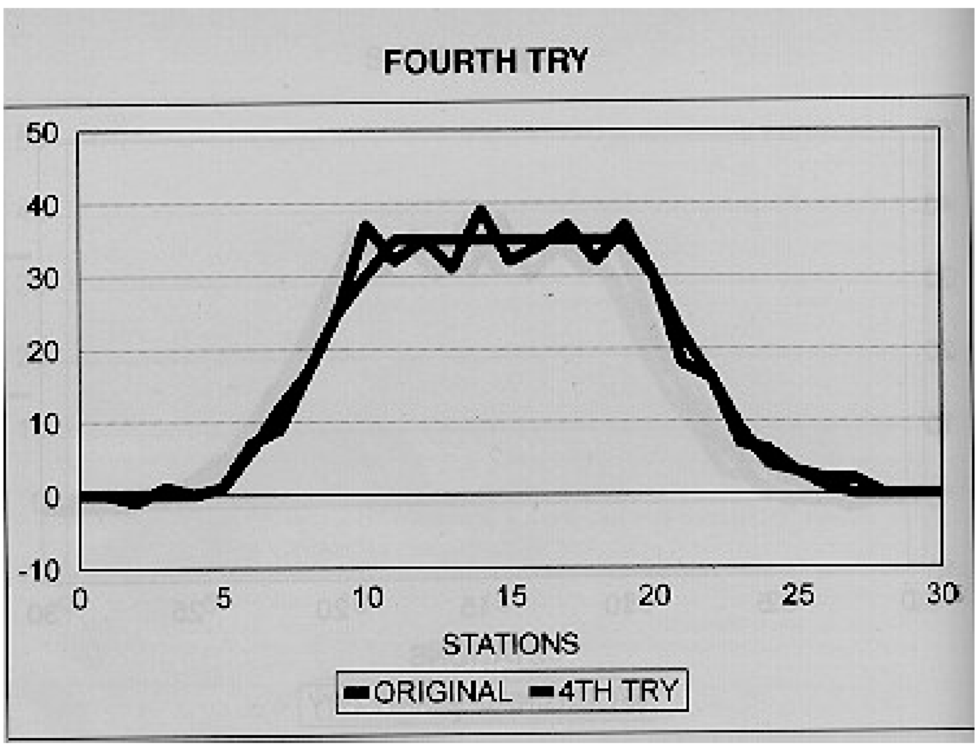


STATION	MID-ORDINATE	REVISED M.O. (2ND TRY)	ERROR (B-C)	SUM OF ERRORS	HALF-THROW	THROW
1	0	0	0	0	0	
2	-1	0	-1	-1	0	
3	1	0	1	0	-1	
4	0	1	-1	-1	-1	
5	1	1	0	-1	-1	
6	7	8	1	0	-1	
7	9	10	-1	-1	0	
8	17	17	0	-1	0	
9	25	23	2	1	0	
10	37	30	7	8	2	
11	32	35	-3	5	11	
12	35	35	0	5	17	
13	31	35	-4	1	23	
14	39	35	4	5	25	
15	32	35	-3	2	31	
16	34	35	-1	1	34	
17	37	35	2	3	38	
18	32	35	-3	0	40	
19	37	35	2	2	41	
20	30	30	0	2	44	
21	18	22	-4	-2	47	
22	16	14	2	0	48	
23	7	10	-3	-3	48	
24	6	5	1	-2	43	
25	3	3	0	-2	40	
26	2	1	1	-1	37	
27	2	0	2	1	35	
28	0	0	0	1	35	
29	0	0	0	1	35	
30	0	0	0	1	35	
TOTALS	489	488	1			



STATION	MID-ORDINATE	REVISED M.O. (4TH TRY)	ERROR (B-C)	SUM OF ERRORS	HALF-THROW	THROW
1	0	0	0	0	0	0
2	-1	0	-1	-1	0	0
3	1	0	1	0	-1	-2
4	0	0	0	0	-1	-2
5	1	1	0	0	-1	-2
6	7	6	1	1	-1	-2
7	9	12	-3	-2	0	0
8	17	17	0	-2	-2	-4
9	25	23	2	0	-4	-8
10	37	30	7	7	-4	-8
11	32	35	-3	4	3	6
12	35	35	0	4	7	14
13	31	35	-4	0	11	22
14	39	35	4	4	11	22
15	32	35	-3	1	15	30
16	34	35	-1	0	16	32
17	37	35	2	2	16	32
18	32	35	-3	-1	18	36
19	37	35	2	1	17	34
20	30	30	0	1	18	36
21	18	22	-4	-3	19	38
22	16	16	0	-3	16	32
23	7	9	-2	-5	13	26
24	6	4	2	-3	8	16
25	3	3	0	-3	2	4
26	2	1	1	-2	0	0
27	2	0	2	0	0	0
28	0	0	0	0	0	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
TOTALS	480	482	0			

Mr. Cloutier: Thank you, Art. For you, too, we have a certificate of appreciation along with one of our coffee mugs.

Mr. Murgas: Our thanks to all the committee chairman who put in their time and effort to make this meeting a success. We saw a lot of good information here. As a matter of fact, when Bill Romig got done with his report, I gave him my card and told him to send me some information about that hydraulic mag generator. That really generated some interest on my part. That's one of the things that the Roadmasters Association is all about. Our purpose is to provide a responsive forum to exchange information among track maintenance professionals.

The committees' efforts and committee structure is the thing that really makes this work. I had several guys stop me outside in the hall as did Bob and Al and we have all been asked what do they have to do to get to be a committee chairman and many expressed interest in putting on a report.

Well, Keith has mentioned this a couple of times. We talked about the green cards. We have the scopes for the subjects next year. We would encourage you to sign up and volunteer to be a committee chairman and give us the benefit of your expertise. I'm not going to sit up here and tell you that it's going to be easy. It takes a little bit of work on your part, but you are going to have a committee that is going to help you. You will have some directors in your executive committee that will help you and you are not going to be out there alone. You will get a lot of help from us.

If you are worried about standing up and speaking in front of a crowd, we even bring in some people to help polish your speaking skills.

If you have any questions about what it takes, come and see me. I would be glad to talk to you. See Bob or see Al or better yet, talk to the chairmen that gave the presentations today. There's not a better source of information about what it takes to put on a presentation than those guys.

Before I turn this thing back over to Keith, I would like to again recognize Bob Davis and Al Cloutier. These guys provided me with a lot of help getting this conference going. Again, it's a team effort and we couldn't have done it without you guys. Why don't we give Bob and Al a big hand. (Applause)

President Nordlund: Thank you, Peter. I can only support what Peter Murgas has said about committee chairman. When I was a chairman, I went through my piece and felt the confidence and the support and then at the end of it, I was quite satisfied and felt quite proud of the job that I had done. I think all the other committee chairmen feel so throughout this conference.

Don't forget the REMSA reception tonight. The hospitality suites will be open tonight as well. If there is no further business, this session is adjourned until tomorrow morning.

Thank you. (Applause)

(Adjourn)