TABLE VIII.—Table of steel bolts.

Size, diameter by length under head.	Average number per keg of 200 lbs.	Number required and weight per mile single track for corresponding rail.								Rail weight per yard.
		Based on 30-ft. lengths.		Based on standard practice, 90% 30 ft., 10% in lengths down to 24 ft.		Based on 24-ft. lengths.		Based on portable lengths averaging 15 ft.		
Ins.		*No.*	*Lbs.*	*No.*	*Lbs.*	*No.*	*Lbs.*	*No.*	*Lbs.*	*Lbs.*
7/8 x 4 3/4	140	2,112	3,017	2,148	3,070	2,640	3,771	......	......	100
3/4 x 4 1/2	220	2,112	1,920	2,148	1,953	2,640	2,400	......	......	95 and 100
3/4 x 4 1/4	230	2,112	1,837	2,148	1,867	2,640	2,296	......	......	85 and 90
3/4 x 4	240	2,112	1,760	2,148	1,790	2,640	2,200	......	......	75 and 80
3/4 x 3 3/4	245	2,112	1,724	2,148	1,753	2,640	2,155	......	......	70
3/4 x 3 3/4	245	1,408	1,149	1,432	1,169	1,760	1,437	2,816	2,299	60 and 65
3/4 x 3 1/2	250	1,408	1,126	1,432	1,146	1,760	1,408	2,816	2,253	55
3/4 x 3 1/4	255	1,408	1,104	1,432	1,123	1,760	1,381	2,816	2,208	50
3/4 x 3	267	1,408	1,055	1,432	1,073	1,760	1,318	2,816	2,109	40 and 45
5/8 x 2 1/2	470	1,408	600	1,432	610	1,760	750	2,816	1,198	30 and 35
5/8 x 2 1/4	492	1,408	572	1,432	582	1,760	715	2,816	1,145	20 and 25
5/8 x 2	525	1,408	536	1,432	546	1,760	671	2,816	1,073	16

Threads can be either United States Manufacturer's or Whitworth's standard.
All bolts furnished with hexagon nuts unless otherwise ordered.
Above numbers allow for no excess.

TABLE IX.—**Weights and dimensions of American standard rail sections.***

Section index.	Weight per yard.	Area.	Width of base and height.	Web.	Width of head.	Height of center of gravity above base.	Axis, $x-x$†		
							Moment of inertia, I.	Section modulus, S.	Radius of gyration, r.
[illegible]	*Lbs.*	*Sq. ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*			
100 A	100	9.8	5¾	9/16	2¾	2.8	43.8	14.6	2.13
90 A	90	8.8	5⅜	9/16	2⅝	2.5	34.0	12.0	1.97
80 A	80	7.8	5	35/64	2½	2.4	26.2	10.0	1.83
70 A	70	6.9	4⅝	33/64	2 7/16	2.2	19.6	8.2	1.70
60 A	60	5.9	4¼	31/64	2⅜	2.1	14.5	6.7	1.58
50 A	50	4.9	3⅞	7/16	2⅛	1.9	9.8	4.9	1.42
40 A	40	3.9	3½	25/64	1⅞	1.7	6.6	3.6	1.30
30 A	30	3.0	3	21/64	1⅝	1.4	3.5	2.3	1.11
20 A	20	2.0	2½	17/64	1⅜	1.2	1.7	1.3	.92
16 A	16	1.6	2¼	15/64	1¼	1.1	1.1	0.97	.84

$$\frac{M}{S}=\frac{\text{Max. bending moment}}{\text{section modulus}}=\text{stress in extreme fiber.}$$

* Am. Soc. C. E. Standard Rail Sections.
† Axis $x-x$ is perpendicular to web of rail section through center of gravity.

TABLE X.—**Maximum allowable wheel loads in pounds.**

C. to c. of ties in ins.	Weight of rail in pounds per yard.					
	16	20	25	30	40	45
20	3,550	4,970	6,390	8,340	12,780	14,920
24	2,950	4,140	5,320	6,950	10,650	12,420
30	2,360	3,310	4,260	5,560	8,520	9,940
36	1,970	2,760	3,550	4,630	7,100	8,280
42	1,690	2,360	3,040	3,970	6,080	7,100

Table IX shows the weights, dimensions, and strength of rails of standard sections, and from this table the necessary weight of a rail can be ascertained for the load to be carried. A rule given by the American Locomotive Co. is that for light rail with properly spaced ties the maximum wheel load may be 250 lbs. for each pound weight of rail per yard under 40 lbs. and 300 lbs. for rails from 40 to 60 lbs. The axle loads of the loaded cars ought to equal the axle loads of the locomotive. This rule is a rough approximation only.

Table X shows the maximum allowable wheel loads recommended by one large manufacturer of portable track.

SUPPLY RAILWAYS.

32. Supply railways include all railways, except combat railways, that may be constructed or used for the supply of an army in the field. They may vary from a light portable track to a standard-gage railway. Their **principal uses** will be to connect the army with its base; to connect permanent camps with the nearest existing railway; to form a belt line around a besieged place outside the field of observation; to form a belt line inside the line of defense of a besieged place; for the movable gun defense, and for a general supply line to supply an army in a permanent position such as the Russian army often occupied in Manchuria. In extreme cases a railway may have to be constructed to supply an advancing army when local conditions preclude other means of transportation.

For cruder forms on which animals are used as the motive power the description already given of a combat railway will suffice. They are what are known as **tramways.** As soon as some form of mechanical traction is to be provided for the line becomes a "**railway**" in the commonly accepted meaning of the word.

33. Regardless of the gage, the same underlying principles govern the construction of all such lines, and, having a plan for the operation and maintenance of an existing line of railway, it is easy to adapt it to the requirements of a temporary line. The **principal considerations** that govern in planning for such a line are, first, the amount of army supplies, troops, and animals that must be handled; second, the time that can be permitted for its construction; and third, which applies particularly to operations beyond the sea, the amount of transportation necessary to place the railway supplies on the work. This third condition will ordinarily necessitate a narrow-gage railway for a supply railway in a country beyond the sea. Local conditions, such as a great supply of standard-gage material and rolling stock, may render advisable the building of a standard-gage railway for operations from a friendly land base; but where conditions extremely favorable to a standard-gage line do not exist, a narrow-gage railway will probably be decided upon in the general case of supply railways. The weight of the materials and rolling stock is so much smaller, the bridges can be so much lighter, and the earthwork is so much less than for a standard-gage road that the narrow-gage railway is decidedly easier and quicker to build.

34. On the Barsi Railway, built in India, a 2 ft. 6 in. gage was used. The weight of the locomotive was 58,800 lbs. in working order; it had an eight-wheel base with a four-wheel pilot truck (bogie), 13 by 18 in. cylinders, and used a working steam pressure of 150 lbs. The rigid wheel base was 8 ft. 3 ins.; total wheel base, 18 ft. 6 ins. The weight on each of the six axles was 10,000 lbs. The sharpest curve on the line has a radius of 175 ft. On a level tangent this locomotive drew 1,036 tons at 15 miles an hour; and on a 1% grade, 9½° curve, it hauled 291 tons at 8 miles an hour.

They were able to run sixteen trains a day in each direction, which, excluding the weight of the cars, carried 3,360 tons each way daily. The load on each car axle was the same as on the locomotive axle—i. e., 5 tons. The weight of rail used was 35 lbs. per yard.

35. General Sherman's army at Atlanta was composed of 100,000 men and 35,000 animals, in a hostile country. The **net train supply** to him was 1,600 tons daily, which he said was in excess of the amount necessary to supply his army. A comparison of these figures shows the great possibilities of narrow-gage railways in supplying troops in the field. However, in using them it must be remembered that the Barsi Railway was a well built and ballasted line, running under peace conditions. Estimates based thereon for war conditions should be reduced enormously to provide for the necessary passenger service and for the interruptions of traffic due to poor track conditions and to accidents incident to a state of war.

36. The **narrow-gage locomotives** built in this country give even better performances than that cited in par. 34, for an eight-wheel locomotive, 14 by 18 ins., class D. T., built by the H. K. Porter Co., of Pittsburgh, weighing in working order 60,000 lbs., is rated with a capacity of 1,875 tons on the level, 425 tons on a 1% grade, and 220 tons on a 2% grade; while class D. T. locomotive, with 11 by 14 in. cylinders, weighing 36,000 lbs., is rated at 1,075 tons on the level, 240 tons on a 1% grade, and

120 tons on a 2% grade. The **axle load** in the first case is 7½ tons; the weight of rail necessary is 30 lbs. per yard. The axle load of the second locomotive is 4½ tons and only requires a 20-lb. rail.

The **rating** of these last two engines is based on the frictional resistance of 6½ lbs. per ton. This resistance may vary from 5 lbs. to 10 lbs. for good cars and track, and may run higher for poor cars and track (see pars. 175, 176).

The **efficiency of locomotives** is being constantly increased, and a study of the latest catalogues of the prominent builders is recommended.

37. The question of **time** not only enters into the question of construction of the road, but is also an important factor as to the amount and kind of narrow-gage rolling stock that can be furnished. For a **short line,** say 10 miles in length, it is probable that the equipment and rolling stock could all be bought from stock. This would mean adapting the grade and gage to the rolling stock, supplies, etc., that the manufacturers had on hand. For a narrow-gage line of **considerable length,** say 40 to 50 miles or more, it will be absolutely necessary to have considerable notice, and the same will be especially true if the material is to be transported across the sea. Under either circumstance, the engineer will first fully acquaint himself with all the plans of the commanding general, and ascertain the general line over which the railway is to be built and the probable army that will have to be supplied. A study of the best maps available will then show him the general features of the country through which the line is to run. On over-sea expeditions the list of material may have to be made up from imperfect knowledge of existing conditions.

If a very accurate and **detailed map** is at hand, the work will be simplified; if not, a general **reconnaissance** should be made of the ground to be covered, where such a thing is at all possible. The engineer will, meantime, enter into communication with the manufacturers of railway equipment of all kinds, and he should then be able to make a bill of material for the railroad that is to be built. If necessary, pressure should be brought to bear on the manufacturers to make them rush his order through without delay and in advance of all other similar civil orders.

SURVEYS.

38. **Routes.**—In some cases it will be possible to go over the route and locate the exact position of the whole railway before construction work commences, and in any case the general line of the road will be known although the exact location may not be determined except as the army advances. In either case, **surveying** will have to be done in order to determine the best line for the road and to locate this line on the ground. Whether this be done in peace or war makes no difference in the general principles, but the circumstances of each particular case will necessitate a judicious determination of the proper care and accuracy that must be used in that case.

39. **Surveys.**—Surveys are location surveys, and construction or final surveys. The instrumental location of a military railroad does not differ materially from that described for a new wagon road, but greater accuracy is desirable, and a much more careful adjustment of curves and grades is indispensable. As with common roads, the grade will mainly follow the natural surface, but the line must be so located as to keep these grades within the adopted limit, which will usually be 2%, though in exceptional cases and for short grades 4% is allowable.

40. **Natural drainage lines** present the most regular and easiest gradients, and in a broad sense it may be said that every railroad location follows lines of drainage. When the head or source of one drainage line is reached, the location crosses the divide to the next. With few exceptions, drainage lines have slopes not exceeding those permissible for railroad location. The first requisite in considering a railroad location is to get the lines of drainage clearly in the mind. This done, start the exploration from the initial point on a straight line for the objective. Keep on this line as long as it can be done within the prescribed limits of grade and curvature. Leave the line only when forced away from it; do not go away from it farther than is absolutely necessary, and get back to it as soon as possible.

41. Before the survey is started, the **maximum grade and degree of curvature** should be decided upon, and in surveying the line the instrument men will know what their limitations are and will locate the line accordingly. This maximum grade should be the **compensated grade.** That is, when the grade occurs on a curve, an allowance of .04% of grade should be added to the actual grade for each degree of curvature to give the compensated grade. When the level man finds the grade running steeper than the limiting grade, he will take a sufficient amount of side notes to determine the **amount of excavation** or filling that will be necessary to keep the grade within the prescribed limits; and if he finds the amount of excavation excessive, he may have to call back the transit man and have the line relocated. This should not happen frequently, as the transit man should know the maximum allowable angle of slope and should locate his line accordingly.

42. The **virtual grade** is the actual grade corrected to take advantage of the velocity head due to the speed of the train when the various grades are encountered. Its principal application is for economical construction, but even at moderate speeds it might occasionally permit the use of grades steeper than the so-called maximum.

43. A **pusher grade** is an isolated case that can not be kept down to the ruling grade nor compensated for by the velocity head. Here it is best to pass at once to nearly double the ruling grade and provide for a regular pusher engine for that special grade. They should not occur oftener than once or twice in a division.

44. It is permissible to increase the total length of the line by 1%, to reduce the ruling grade 0.1%. This is an English rule and is subject to many limitations. It would only apply to the division in which the grade lay. It does not take into account the difference between the actual profile and the virtual profile, and it does not contemplate the use of **pusher engines** on isolated heavy grades. It apparently is meant to apply where the ruling grade is used very frequently through the division.

45. The combination of notes of the transit and level parties will show the grades and the curves that will be necessary, and will thus determine the practicability of the route selected. Below the limiting grade that a lone locomotive can ascend, the **working maximum grade** for the line will be different in every case and there is no such thing as a fixed maximum. The only general rule is to keep it as low as practicable and still keep the amount of construction work within reason. Par. 175 describes the method of finding the **tractive power** of a locomotive. Knowing the available rolling stock, the amount of supplies to be transported, and the nature of the country, the maximum grade will always be a compromise between what you can get and what you would like to have. Pars. 34 and 36 show that grades above 2% are almost prohibitive. The maximum degree of curvature is not so indefinite. There is a railway in Colorado with **50 curves of 20°**, or more, in 11 miles. The Baltimore and Ohio, until recently, had a **300-ft. curve** at Harpers Ferry on its main line. The 175-ft. curve (par. 34) on the Barsi road could undoubtedly be made sharper and still be practicable. With these as limits, a road can wind in and out through almost any country. Keep in mind that **sharp curves are preferable to steep grades** if it becomes a question between the two.

46. The **maximum allowable degree of curvature** is a function of the rigid wheel base of the locomotive and the amount of clearance between the inner flanges of the rails and of the locomotive wheels. The generous use of curves to avoid heavy cuts or fills is economical of time in construction and the relation between the resistance due to curvature and that due to grade is shown by the compensation for curvature referred to in par. 41.

47. It is assumed herein that the officer in charge of the work is acquainted with the use of instruments, and so no explanation is made of the instruments nor of the methods of using them.

Upon the completion of the survey and the determination of a practical route will come the **location** of the **line of track.** This may either be done by the preparation of a map whereon are plotted the cross sections taken, or the profile may be plotted and any objectionable features, such as excessive grades, cuts, or fills, can be corrected by the necessary deviation when the engineer reaches that point in the line in the course of the actual, final location. In the first case, the center line having been plotted, where no cross sections have been taken, it is assumed that the track may be moved 100 ft. in either direction without changing the elevation materially. Where the cross sections have been taken, the desirable center line is indicated by a series of points and the center line of the track is located to correspond approximately to these points. The line along the part not cross-sectioned is then shifted to one side or the other to correspond. Theoretically, this is the best way to locate a line of railroad; in practice, however, railroad locating engineers become expert in the location of lines on the ground, and due to inaccuracies which occur in all maps, it is usually found that the engineer will have to change the center line more or less, no matter how carefully it was located on the map.

In ordinary practice the line is actually located on the ground by the instrument men at the head of the locating pa ty, and any necessary corrections are made in the same way.

48. A **profile** will be made showing the elevations of the center line finally decided upon, and by means of pins and threads the exact elevation and grade of the line can be determined for every station. In this determination the notes taken by the transit party regarding the class of soil, rock, etc., should be considered.

49. The foregoing description of the method of location sounds cumbersome, but the actual work can be kept up so that before going to bed at night the locating engineer has determined the line and grade of his track up to the end of the day's work, or else has determined that that particular line will not satisfy the limiting conditions of the case in hand. In either case, the next morning the party is prepared to continue work, or to start afresh at some point back on the line, knowing that the work up to the point of starting has thus far determined a satisfactory location for the line.

50. In a very **rough country** it may be found advisable to use a plane table in the construction of the map for determination of the route; the advantage of this method is that a map of a certain area can thus be obtained with a great deal less labor than by the use of the transit and level. The plane table is especially useful for mapping bridge sites, but for general location has not been found as practical as the method of transit and level.

51. **Instruments** should be checked as to their **adjustment** often enough to keep the instrument man confident of their approximate adjustment. For methods of adjusting instruments, see Part I, on Reconnaissance.

52. **Sidehill work.**—In locating the line on the side of a hill the center line should be run along the surface of the ground, if this can be done by a slight movement to one side or the other. This will equalize the necessary amount of cutting and filling, and will minimize the movement of material.

53. **Estimates.**—After the location survey has been made, notes are then at hand for making an estimate on the amount of material that must be moved, the other work that must be done, and the time necessary to build the proposed line. The estimates are made, if the work is to be done by contract, to obtain a basis on which the contract shall be let and upon which payment will be made; but in the normal case of a military line the work will be done by troops, or by hired labor, and the **object of the estimate** is to determine the quantity of work to be done at different points along the line in order to so subdivide the working parties as to get the best results and the quickest return in the shape of completed line.

In case an **official report** is desired by the commanding general before he decides whether or not to construct the line, the entire survey and the estimates must be finished before this report is made. This report will be accompanied by maps and profiles showing the routes considered and the final location decided upon, and the reasons therefor. It will also show the approximate cost of material and of civilian labor, the amount and cost of rolling stock and other equipment, and will show the capacity of the line when it is completed and the time that will be necessary to complete the work as desired. In case it has been definitely decided in advance to build the line, the cost and time are only considered in that they must be kept as low as practicable, and the survey need not be completed before construction work begins.

A short section of location 4 or 5 miles in length is completed so that the working parties can be started, and thereafter it will be an easy matter for the survey parties to keep well in advance of the construction parties, since it is hardly practical for the construction party to average over 1 mile a day if conditions as to weight of track number of bridges, and amount of excavation are not peculiarly advantageous. Even under favorable conditions as to construction, and with the use of light track, probably not over 3 miles a day can be finished. The survey parties can easily make more than this and will be able to keep ahead of the construction parties. (However, see par. 115.) It took 173 days to build 190 miles of the 3 ft. 6 in. railway from Wada Halfa to Abu Hamed in 1897, on the latter part of which as much as 5,300 yards of line was built in a day. This road was built by Lieut. (now Col. Sir.) E. P. C. Girouard, R. E., British Army.

54. A line of railway is made up of curved and straight lengths; the former are called **curves** and the latter **tangents.** Railroad curves are usually arcs of circles. They may be either simple, compound, or reverse. A **simple curve** is a curve with a constant radius. A **compound curve** is one composed of two or more simple curves of different radii curving in the same direction and having a common tangent at their point of meeting. A **reverse curve** is composed of two simple curves curving in opposite directions and having a common tangent at their point of meeting. The name is also commonly applied to two simple curves curving in opposite directions, which are joined by a tangent shorter than the usual length of trains running on the line.

55. A **transition** or **easement curve** is a compound curve, or spiral, used at the ends of a sharp curve to lead gradually from the tangent to the main curve.

56. A curve with a radius of less than 500 ft. is commonly referred to by its radius; as, a curve with 150 ft. radius, or a 150-ft. curve. Curves with radii longer than 500 ft. are usually designated by the number of degrees of arc that a chord 100 ft. in length subtends from the center of the circle. Thus, a 5° curve means that a 100-ft. chord subtends an angle of five degrees (5°) from the center of the circle. There are other means used to designate curves of very short radii, but they are more or less misleading; as, for instance, $8°_{25}$, which signifies that a chord of 25 ft. on the circumference subtends an angle of 8° at the center. A **curve is measured** along its chords, and such length of chord should be assumed that the ratio of the arc to the corresponding chord is practically unity. The number of subtending chords multiplied by the length of such chords equals the length of the curve L. $L=\frac{\Delta}{D}l$, where Δ=central angle, D=degree of curvature, l=length of chords used.

A **1° curve** is considered as the basic curve and its elements are shown in Table XIX for use in computing data for curves of other radii. Its radius is 5,729.65 ft. and a 100-ft. arc of such a curve subtends 1° at the center of the circle. The corresponding functions or elements of any two curves are proportional to their radii and therefore those for a curve of 5° are found by dividing the corresponding elements of a 1° curve for the same central angle, by 5. This rule holds good as long as the 100-ft. chord and the subtended arc are not sensibly different in length.

57. The various **parts of a curve** are shown in fig. 27. We are supposed to be moving in the direction FBH. FB is one tangent joined to BH, another tangent, by the curve ADC. The angle between FB, extended, and BH is called the **external, or central, angle** (Δ). B is the **point of intersection,** usually designated P I. A is the **point of curve** (P.C.). C is the **point of tangent** (P.T.). O is the center of the arc. AC is the **long chord** (C), ED is the **middle ordinate** (M), and DB is the **external distance** (E). AB and BC are called the **tangent distances** (T). AO is the **radius** (R). The **degree of curvature** is D.

The relations between the various angles and lines can be seen from the figure. Various formulæ showing the relation of the different parts to one another are given in Table XVII.

58. **Method of laying out curves.**—These methods vary greatly, and each depends largely upon the local accidents of the terrain. A few of the simplest are given here. In running a tangent along the line FB (fig. 27), the point B is reached where the direction of the line changes to BH. The exterior angle Δ is measured, and it is desired to put in a curve connecting the tangent FB with the tangent BH. Either the radius or the degree of curvature must be assumed before the points of tangency can be located. If the ground inclosed in the triangle ABC is clear and open, practically any curve can be run between the two tangents. Sometimes, however, there is some condition that determines where the curve shall lie and consequently what the radius of curvature will be. A common condition is that the point D in the curve is fixed by some local condition, thereby fixing definitely the length of the line BD. A reference to Table XVII will show the relation of the line BD (usually referred to as E) to the other parts of the diagram, and from this table, knowing the external angle Δ, and measuring E, R can be determined. $R = \frac{E}{\text{ex. sec. } \frac{1}{2}\Delta}$

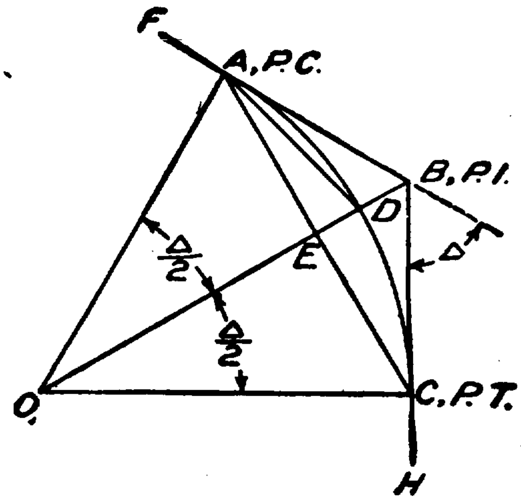

FIG. 27.

Given R, and Δ, the distance AB and BC can be determined, since $T = R \tan \frac{1}{2}\Delta$.

Such a condition might arise in siege works, when the point D must lie in the bottom of a trench already dug.

Curves are usually laid out by use of the transit, but for rough work or in an emergency they may have to be laid out **without the aid of an instrument.** For such occasions the following methods are described:

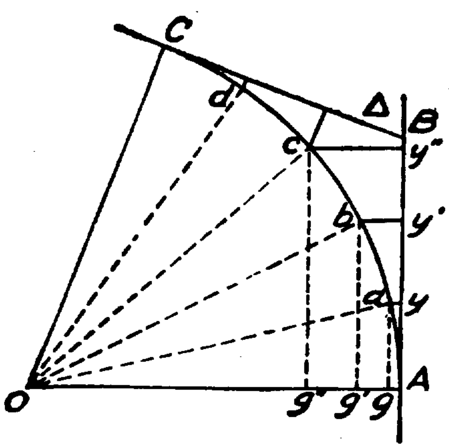

FIG. 28.

59. **The method of offsets from tangents** (see fig. 28).—Knowing the P. C., P. T., and R, make a table for tangent distances and offsets. The distances on the tangent A*y* from the P. C. to the perpendicular offset from the extremity of any arc, A*a*, is equal to R sin D for the first station and R sin (*n* D) for any succeeding station (*n* being the number of the station from the P. C.); and any offset, as *ya*, from the tangent to the extremity of any arc is equal to R vers (*n* D). Make up a two-column table, in one column of which are placed the distances to be measured along the tangent, and in the other the perpendicular offsets from the tangent to the points in the curve. Having the tangent distances corresponding to the consecutive chords for half of the curve and the offset for each, measure off the distances from the P. C. along the tangent and locate each by a peg; then at each peg lay off perpendicular to the tangent the corresponding offset from the column of offsets. This locates half of the curve. Go to the P. T. and locate the other half of the curve from that point.

60. A **simpler form** of this same method by offsets from the tangents will be found by using Table XI. This table gives the perpendicular offset for a curve with