Design of Light Rail Transit Catenary Systems that Encourage Universal Contractor Participation

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A catenary is a curve formed by a free falling inextensible cable loaded uniformly along its length. This closely approximates the form taken by overhead power systems so, within the industry, the term "catenary" has come to represent overhead power systems (including support systems and insulators) the purpose of which is to furnish traction power to electric rail vehicles (Figure 1).

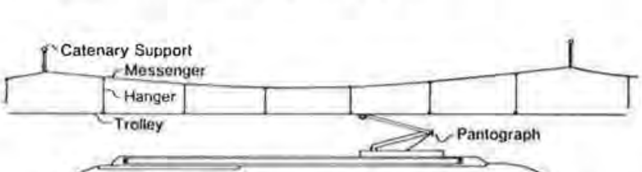

FIGURE 1 Catenary system.

The messenger cable serves as electrical feeder and as support to the trolley wire that in turn distributes power through contact with the vehicle-mounted current collector or pantograph. The catenary was sized to meet future power requirements of Port Authority Transit (PAT) of the Port Authority of Allegheny County, Pennsylvania, without parallel feeders. Such feeders were not cost-effective and would have created problems in areas of tight right-of-way. Additional overhead or underground lines were therefore avoided along with the frequent taps that go with them.

The easy way for an authority to specify a catenary system is to choose a system that has been used before, providing that it meets operating and maintenance requirements. This would appear to be the safest approach assuming that prior experience can assure timely completion and reliable function. But, as illustrated hereafter, with catenary, tried and true is not always the best route to successful construction.

- There are few manufacturers who make "off the shelf" catenary system material. Also, there are a limited number of experienced contractors who have successfully installed catenary.
- It follows that, where prerequisites for supply and installation are overly restrictive, competition will suffer causing prices to rise.
- Available systems may not be suited to the particular location or to the operating requirements the owner has in mind. For example, the need to minimize the number of supporting structures led to the development and use of two-track brackets, which are not normally available.
- A limited or single line of supply for equipment can delay construction if the source becomes unreliable. This can also cause future operating problems when maintenance items cannot be procured reliably.

All these potential problems faced the Port Authority of Allegheny County during the preliminary design phase of its Stage 1 light rail transit system. But, with the support of its engineering consultant, Parsons Brinckerhoff-Gibbs & Hill (PBGH), PAT chose to widen the field of contractors able to participate in the manufacture and installation of catenary systems.

This path is not without its pitfalls and liabilities but, with the aid of the ensuing descriptions and history, the benefits will be apparent. Figure 2 shows a 40-year-old Presidents' Conference Committee car operating on the new catenary system in Pittsburgh.

FIGURE 2 PCC car on new catenary system.

CATEGORIES OF CATENARY EQUIPMENT USED

Where possible, equipment widely used and manufactured was specified. In most cases at least two sources for each of the following items were identified:

- Catenary hanger assemblies comprised of bronze rod with messenger and trolley wire clamps (Figure 3); specified as either Dossert or Ohio Brass catalog items.
- Parallel electrical connectors used with flexible feeder cable to electrically connect messenger and trolley (Figure 4); specified as Burndy, Dossert, or Ohio Brass catalog items.
- Cable dead end connectors (Figure 5) used at insulation points required for sectionalization or cable dead ends and specified as Nicopress, Burndy, Dossert, or Ohio Brass catalog items.
- Dead end insulators (Figure 6) used at catenary system dead end (cable terminations at structures) locations; specified as an Ohio Brass catalog item.
- Section insulators (Figure 7). Various types of section insulators were evaluated during pantograph trials on Pittsburgh's 1/2-mi test track. The Ohio Brass section insulators met all system requirements, were in wide use on other U.S. properties, could be delivered in quantity relatively quickly, and were therefore specified. This insulator was also used by PAT maintenance in conjunction with trolley pole current collectors. PAT was therefore comfortable with the Ohio Brass product before LRT construction.
- Support and curve pull insulators (Figure 8). Various manufacturers' products were investigated, but, for the combined low insulation (650 V DC) and high mechanical (2,000 lb horizontal) requirements, H.K. Porter catalog items were specified.

When equipment was unavailable or sources were unreliable, new products were developed with the help of cooperative manufacturers. Many manufacturers were contacted and at least two were identi-

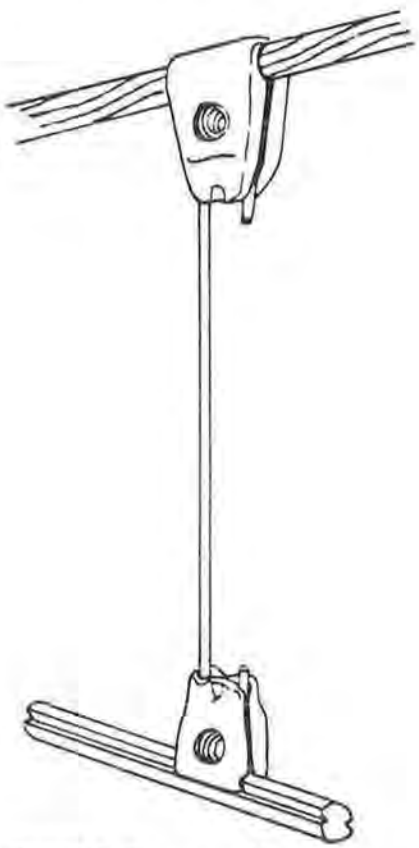

FIGURE 3 Hanger assembly.

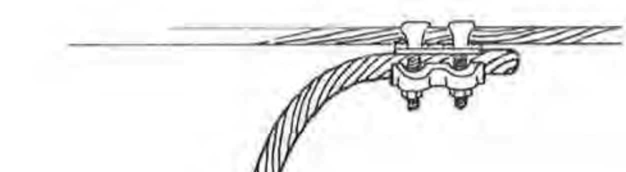

FIGURE 4 Parallel electrical connector.

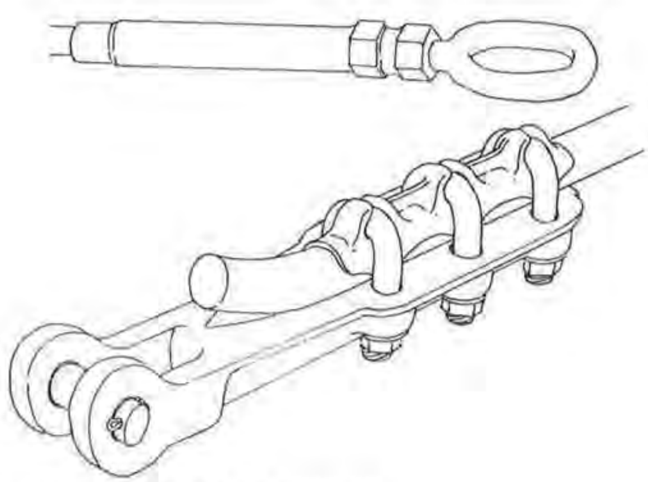

FIGURE 5 Cable dead end connectors.

FIGURE 6 Dead end insulator.

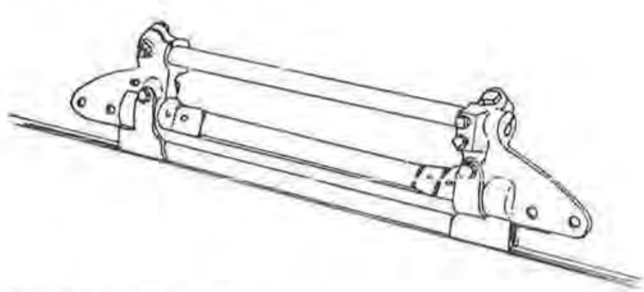

FIGURE 7 Section insulator.

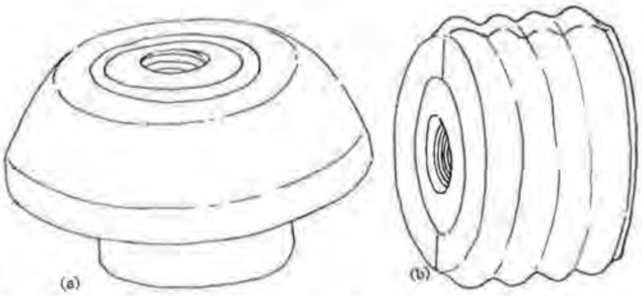

FIGURE 8 Support insulator (a) and curve pull insulator (b).

fied as potential suppliers for each of the following items:

• Messenger and trolley wire clamps (Figure 9). Some clamps were available that could have met the mechanical requirements, but these items were expensive and not commonly used (therefore in short supply). Dukane Mining Co., a Pittsburgh mining equipment manufacturer, was willing to modify their standard clamps to meet Pittsburgh requirements. These clamps were successfully supplied at a competitive price by Dukane and H.K. Porter.

• Pull-off arm insulators (Figure 10). The catenary double insulation requirement necessitated the placement of the primary insulator as close to the trolley wire as possible. Various designs were evaluated and the one chosen uses a standard cylindrical insulator threaded and epoxied to steel pipe sleeves.

• Bracket insulators (Figure 11). The double insulation requirement necessitated the placement of the bracket insulator as close to the catenary pole as possible. PBGH established electrical and mechanical requirements from which insulator manufacturers were able to develop a new product. The bracket insulator is now available as an H.K. Porter catalog item.

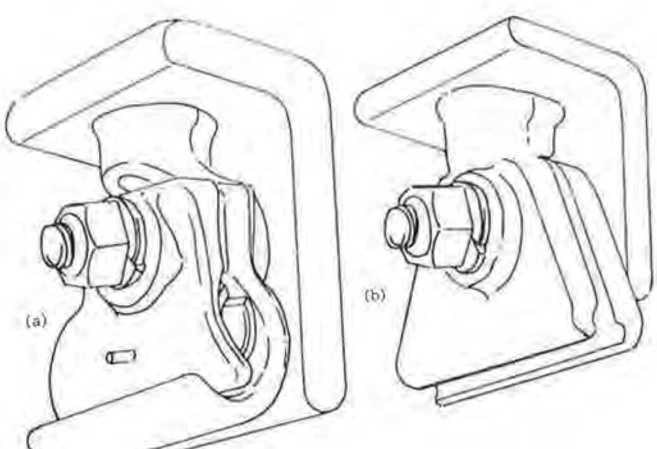

FIGURE 9 Messenger clamp (a) and trolley wire clamp (b).

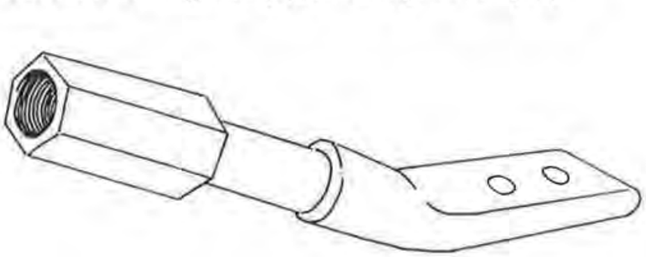

FIGURE 10 Pull-off arm insulator.

When possible, detailed design drawings were produced that enabled many small manufacturing firms to supply equipment at extremely competitive prices:

• Bracket tubes (Figure 12). The catenary brackets are manufactured of standard square and rectangular steel tubes specified as ASTM A500, Grade C. The tubes were also required to meet an impact requirement of 15 ft-lb at 20°F to guard against brittle fracture, which is common in structures of this sort subject to cold weather. The tubes are standard components throughout the Pittsburgh LRT system and are used in conjunction with pole brackets, subway supports, and portal frames.

• Fastening concept (Figure 13). The catenary

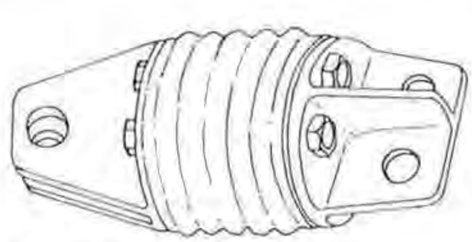

FIGURE 11 Bracket insulator.

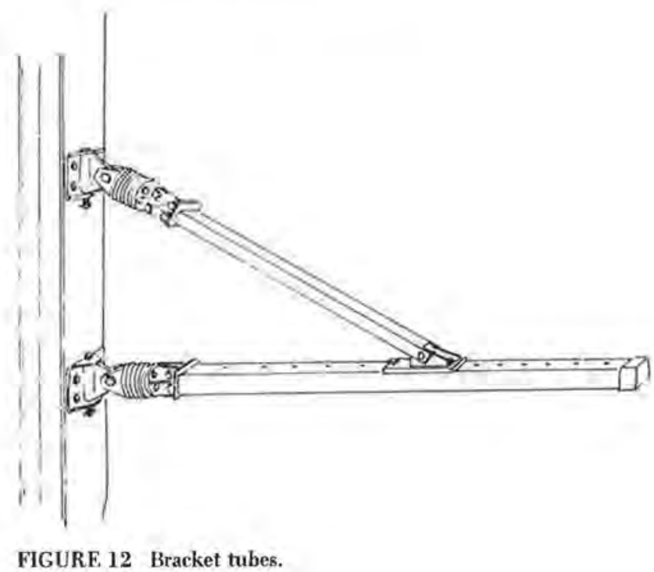

FIGURE 12 Bracket tubes.

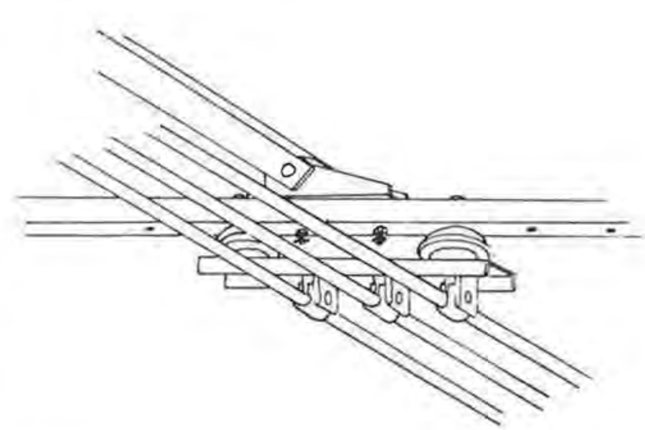

FIGURE 13 Fastening concept.

support was designed to accept normal (and in most cases abnormal) track and foundation construction tolerances. This adjustability was accomplished by setting attachment points at 6-in. intervals in the general vicinity of all connections. Each attachment point consists of a steel pipe inserted through a hole in the bracket tube and welded in place. In this way adjustability was provided, the tube was strenghtened through placement of pipe, and the assembly was sealed to prevent corrosion.

• Bracket hinges (Figure 14). Hinges of this type have been used before but none were able to meet the Pittsburgh LRT system strength requirements. A simple hinge was designed that gives the manufacturer the option of using a weldment or a casting. Both options were supplied competitively.

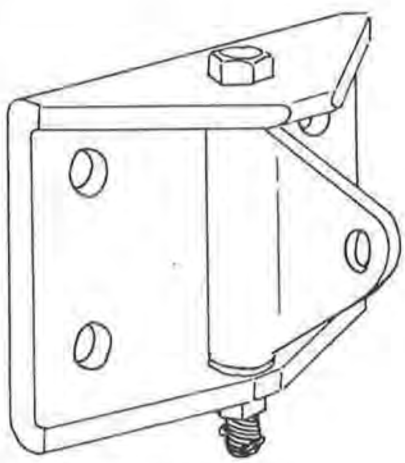

FIGURE 14 Bracket hinge.

• Pull-off arms (Figure 15). Pull-off arms on the market were unable to meet Pittsburgh's strength requirements. Therefore a simple bent solid steel bar flattened and drilled on one end and threaded on the other was designed by PBGH and subsequently supplied by Cleveland City Forge.

FIGURE 15 Pull-off arm.

Figure 16 shows a typical center pole with catenary support brackets attached. The uppermost wires are signal, communication, and electrical feed cables.

PRICE

The material price tabulation given in Table 1 documents prices paid over a period of 3 years for the catenary equipment discussed previously. Material was bought through six separate procurement contracts, and in every instance a basic downward price trend is shown for the item. There are a small number of single price exceptions that can be noted on the tabulation. These were caused by bidder errors or

FIGURE 16 Typical center pole.

irregular pricing conditions; however, if the item prices for each procurement are totaled and compared (Figure 17), the trend to lower prices over the bidding period is evident (34 percent reduction over 3 years). A total of some 20 companies were involved in competitively bidding the six contracts. Economic conditions were such that manufacturers found these items attractive money makers. All but the first contract had an abundance of bidders, both local and nationwide.

CATENARY EQUIPMENT INSTALLATION

Specifications for catenary installation were drawn up in great detail and emphasized the step-by-step procedure and close tolerances that are required. With this cookbook-type approach, firms with limited overhead wire stringing experience were able to bid and perform the work successfully. The following specification segments are offered in this section:

• Bracket installation, which commences after pole and foundation installation and provides messenger and trolley support;

• Messenger stringing, which enables hinged brackets to be held in place and provides support to trolley;

• Trolley stringing--hung from messenger and positioned via pull-off arm system; and

• Temperature and tension curves, which allow wire tensions to be applied after stringing.

TABLE 1 Material Price Tabulation for Catenary Equipment

Product List No.	Category[a]	Description	Unit Price ($) on 6/81	2/82	12/82	2/83	1/84	7/84
100	A	Curve pull insulator	10.78	16.28	20.50	7.30	11.26	9.05
101A	A	Support insulator	17.45	27.28	35.53	10.05	17.65	14.75
98A	B	Large messenger clamp	22.53	28.15	49.46	29.15	21.61	18.10
99	B	Trolley wire clamp	21.45	30.54	49.85	17.50	21.13	19.60
239	B	Pull-off arm insulator	27.35	33.33	36.08	88.08	25.92	22.65
221	B	Crossarm insulator	75.50	82.44	117.02	27.66	49.16	45.84
219D	C	6 x 4 x ¼ tubular crossarm	848.65	815.75	389.00	607.70	529.04	521.32
220C	C	3 x 3 x ¼ tubular crossarm	139.35	177.47	76.77	96.90	106.02	103.86
222A	C	Connection plate (fastening concept)	13.08	12.48	13.61	20.13	7.13	7.15
245E	C	Bracket hinge	48.00	85.23	49.63	16.73	54.58	49.35
226	C	Pull-off arm	49.00	43.43	39.47	18.42	32.76	27.57
Total			1,273.94	1,352.38	876.92	939.62	876.26	839.24

[a] A = widely used and manufactured, B = new product developed by cooperative manufacturers, and C = new designs specified.

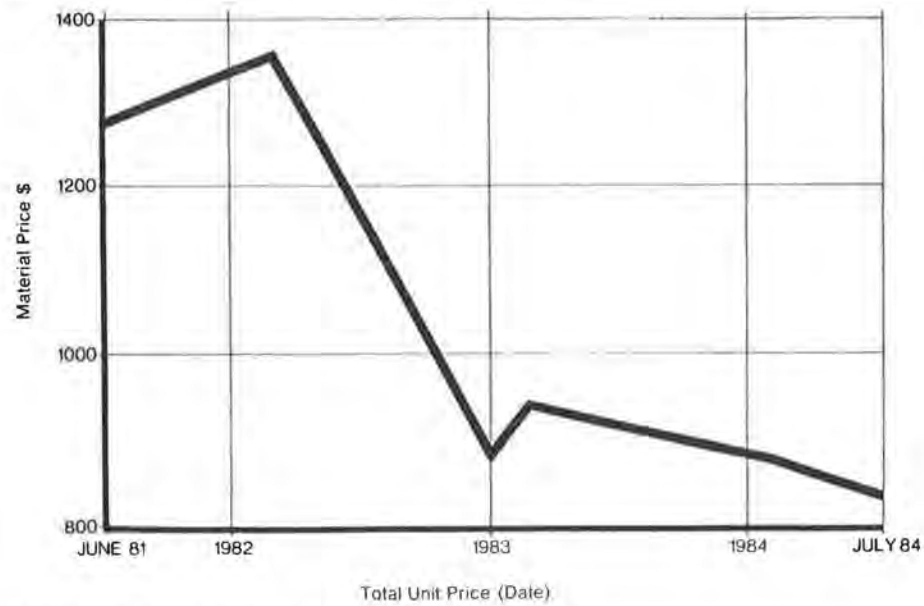

FIGURE 17 Material price chart.

Bracket Installation

1. The poles and foundations shall be installed before installation of catenary brackets (Figure 18).
2. Install hinges on poles. Tighten bolts using ASTM A325 turn of nut method.
3. Install insulators to crossarms and sag braces.
4. Using a hydraulic lift road vehicle or equivalent piece of equipment, lift the crossarms and sag braces, and attach to hinges.
5. Lift the crossarm to a horizontal position, and attach sag brace to crossarm.
6. Adjust the sag brace connection until the crossarm is horizontal (using slotted holes or moving connection plate).
7. If a two-track bracket is being erected, the longest sag brace shall be installed first.
8. Check movement of bracket to ensure hinges and pins do not bind.
9. Using an approved megger instrument, the contractor shall ensure the function of bracket insulators.
10. To prevent possible damage, the bracket shall be temporarily guyed. A temporary eyebolt,

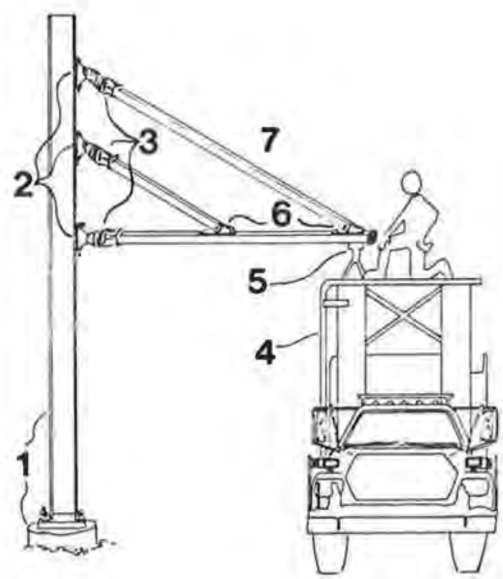

FIGURE 18 Bracket installation.

attached to the crossarm, may be used for this purpose. These guys may be removed when the first messenger is strung, tensioned, and clamped to the bracket.

Messenger Stringing

1. Messenger hardware shall be attached to crossarm in accordance with contract drawings.
2. Attach a stringing block near the final wire position, possibly suspended from an eyebolt fastened to the crossarm, on brackets to be used for this wire-stringing sequence (Figure 19).

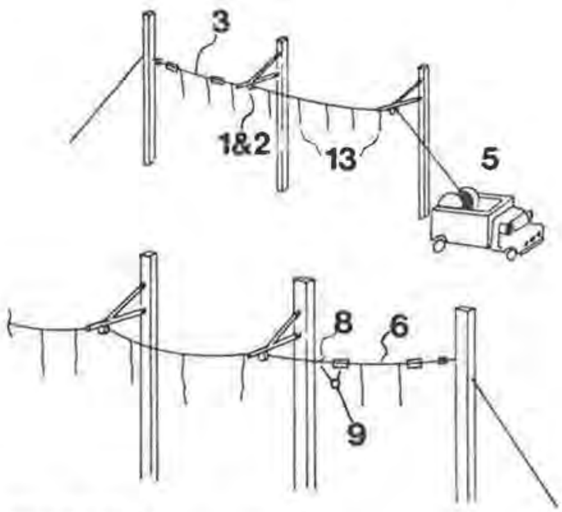

FIGURE 19 Messenger stringing.

3. Attach dead end tail to dead end pole.
4. Align bracket in proper position disconnecting and reconnecting temporary guys as necessary. At no time shall brackets be permitted to stand freely without guy or messenger in place. Proper position of the bracket shall be in the direction of the resultant created by the radial load or loads of the wire or wires.
5. A vehicle with a drum carrier and jib is required for the following: (a) Connect a strain clamp to messenger and dead end tail and slowly move the vehicle throughout the wire run length, hooking wire over the stringing blocks as the vehicle traverses through the section pulling the wire. (b) During installation, contractor shall tension wire as necessary so final wire tensions can be obtained on completion of the tension length.
6. When termination span is reached, attach the dead end tail to dead end pole.
7. Attach thermometers to the messenger wire to establish average temperature over the tension length.
8. Attach wire grips to the messenger wire and termination strand.
9. Attach hoist and tension gauge (dynamometer) to the messenger. Take up tension and cut messenger from drum.
10. Using the hoist, apply appropriate tension (see Tension Temperature Charts later in this paper) required for the catenary's equivalent span.
11. Traverse through the tension length and transfer the messenger from the stringing block into the respective messenger clamp, as depicted on the contract drawings, securing messenger in clamp but not tightening the clamp through bolt.
12. Using an approved megger instrument, the contractor shall ensure the function of all insulators.
13. As the tension length is traversed, install temporary loop hangers (1/8-in. steel strand) within 6 in. of the permanent hangers.
14. Remove temporary bracket guys.
15. Installed messenger, longer than 2,500 ft, may contain one splice, the location of which shall be subject to approval by the engineer.
16. Installed messenger, 2,500 ft long and less, shall not contain any splices.

Trolley Wire Stringing and Hardward Installation

Figure 20 shows a local electrical contractor stringing catenary trolley wire.

Installation is done in the following manner (Figure 21):

1. Attach a stringing block to the drop bracket on each structure to allow the wire to pass through in its approximate final position.

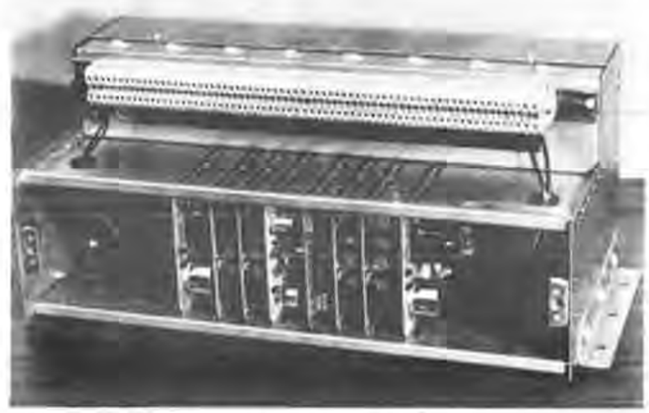

FIGURE 20 Catenary trolley wire stringing.

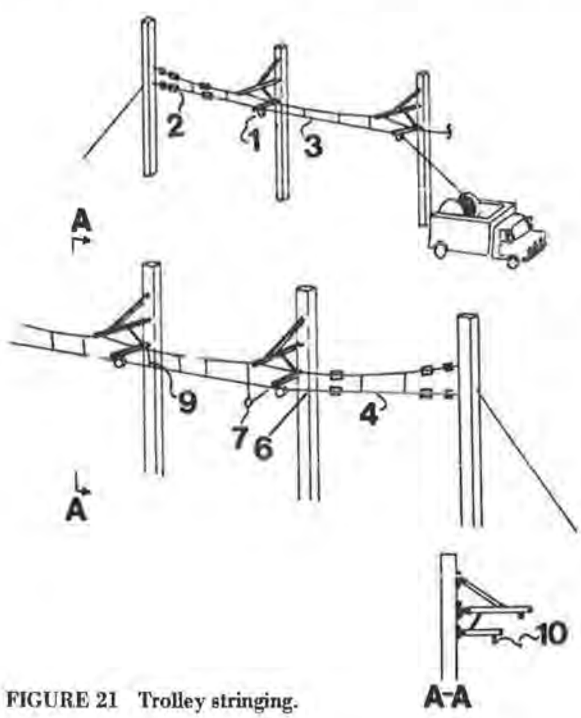

FIGURE 21 Trolley stringing.

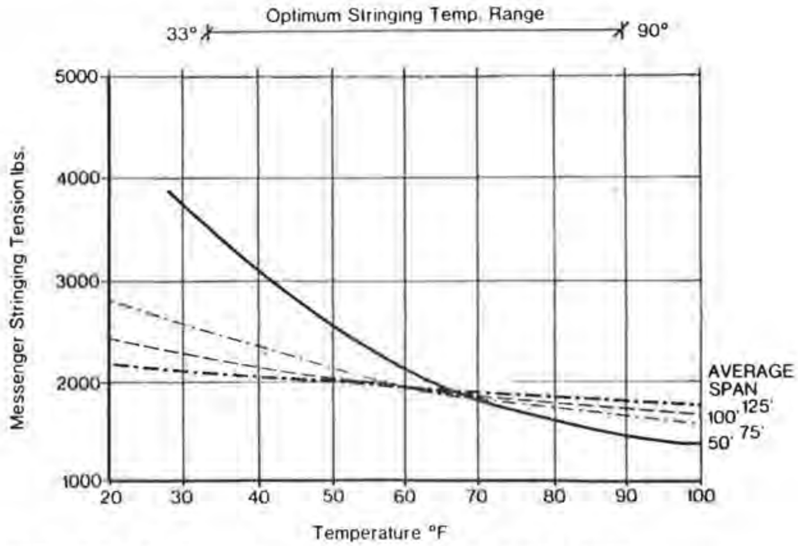

FIGURE 22 Tension and temperature chart (unloaded) for 1000 kcmil messenger.

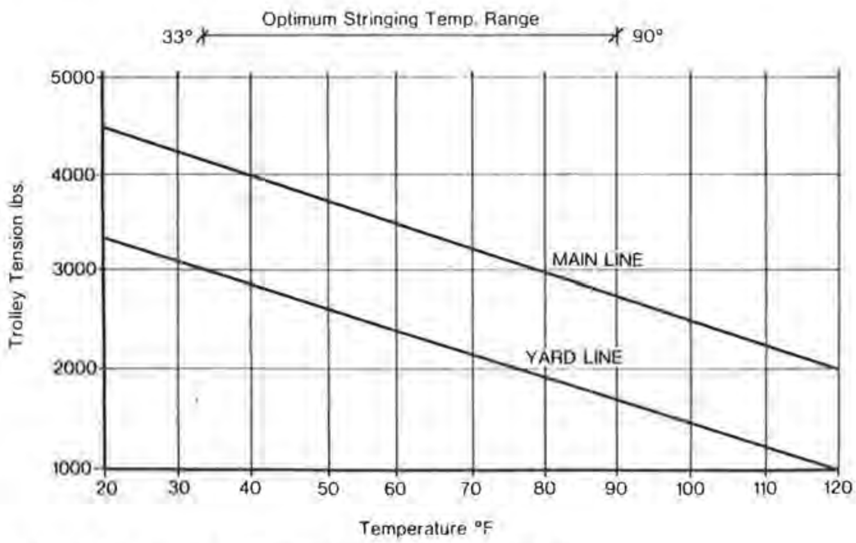

FIGURE 23 Tension and temperature chart for 4/0 trolley.

2. Attach dead end tail to dead end pole.

3. A vehicle with a drum carrier and jib is required for the following: (a) Attach a dead end clamp to the trolley wire and connect to dead end tail. (b) The trolley wire shall be strung with bottom lobe down and free of twists. (c) Traverse through the section supporting wire on temporary loop hangers and through stringing blocks. (d) During installation, contractor shall tension the wire as necessary so final wire tensions can be obtained on completion of the tension length. (e) Attach trolley hanger clamps at the approximate hanger locations, to assist in maintaining the grooved trolley wire in the correct plane during wire installation.

4. When termination span is reached, attach the dead end tail to dead end pole.

5. Attach thermometers to the wire to establish average temperature over the tension length.

6. Attach wire grips to the termination strand and trolley wire.

7. Attach hoist and tension gauge (dynamometer) to trolley wire. Take up tension and cut wire from drum.

8. Apply appropriate tension (see Tension and Temperature Charts later in this paper).

9. Traverse through section, install final hangers, and remove temporary loop hangers. Contractor shall field verify span lengths. Where span codes for these lengths are not indicated in the contract drawings, the contractor shall consult the engineer for the required information.

10. Traverse through the tension length, attach pull-off arms to trolley.

11. Transfer wire from pulley to trolley wire clamp, tighten the clamp to support the wire, but allow it to slide through, and remove pulley.

12. Using an approved megger instrument, the contractor shall ensure the function of all insulators.

13. Allow catenary to stand for 48 hr.

14. Tension messenger and trolley to final tension, adjust hangers, and pull-off arms and guys.

15. Tighten messenger and trolley wire clamps after final tensions have been set.

Temperature and Tension Charts

The catenary system installed in Pittsburgh is the variable tension type with fixed dead ends. Therefore tensions vary with the wire's thermal expansion and contraction characteristics and the contractor requires a chart relating tension to temperature. Figures 22 and 23 show charts that were calculated to provide level trolley wire at 60°F. Above 60°F the trolley will sag and below 60°F it will curve upward or hog (unless the system weight is increased due to the formation of ice on the conductors). The temperature and tension charts shown are for both the "main-line" and the "yard" catenary systems used for Pittsburgh.

CONCLUSION

Any transit authority that finds itself in the position that PAT was in before design and construction of catenary systems must make a choice. The authority can put time, effort, and money into development of a standardized system that will precisely meet their criteria at the very outset of a project thus ensuring competitive prices, consistency in supply and installation, and future availability of material. Or, an authority can choose the cheapest initial course using available equipment and installation techniques that can easily lead to high material and construction costs. The latter can also lead to an overdependence on limited sources; and, should a sole source "dry up" unexpectedly, construction or maintenance, or both, will suffer. The Pittsburgh LRT system is a good argument for the first choice. A standardized catenary system was developed and was made to be easily manufactured and installed. Prices were competitive and equipment was quickly available from any number of sources. In addition, the authority had enough time in the planning stages to modify equipment to suit any requirements specific to the location, and there was sufficient time during the preparation of contract documents to become familiar with the detailed workings of the system. Planning and designing ahead in this manner have benefited the authority on all levels.