Transmission tower development in the UK

C. Lomas

National Grid Company, National Grid Offices, Woodbridge Road, Guildford, Surrey GU1 1EJ, UK

This paper looks back on the development of the lattice steel tower and the use of lattice towers on overhead transmission lines in the UK over the past sixty years. It reviews the current regulations and the National Grid Company's approach to alternative tower types.

Keywords: towers, lattice, steel poles

When the electricity supply industry was privatized, the National Grid Company plc (NGC) inherited responsibility for the high voltage transmission network throughout England and Wales from the Central Electricity Generating Board (CEGB).

In total NGC owns and operates an overhead line grid system of approximately 7000 route kilometres at 275 kV and 400 kV. The major development of the supergrid took place in the 1950s and 1960s and, since then, new construction has been limited to relatively short stretches of overhead lines providing new exit and entry points to the grid.

Following privatization and the open market in electricity generation, a number of new generators have entered the pool. With generation no longer centrally planned, the pressure on the grid system will grow and NGC will face the need to reinforce the transmission network in an increasingly more environmentally conscious climate. NGC has therefore been looking to extend its vocabulary of transmission tower designs in order to be in a position to offer alternatives if these are seen as less visually intrusive or more acceptable solutions in certain environments.

This paper looks back at the development of the standard lattice tower designs which have led to the current elegant L12 double circuit tower and examines alternative solutions, a number of which are now in fairly common use in Europe and North America. Indicative cost ratios are given for the alternative forms of construction.

Development of lattice tower design

Since the 1920s when the Central Electricity Board (CEB) was charged with the duty of building and operating a transmission network, pylons have been synonymous with the grid. It was accepted that there was no way that power lines, especially the pylons, could be made unobtrusive, but something could be done to prevent them from being positively ugly. So the CEB commissioned Sir Reginald Bloomfield to help in designing a tall, widespread pylon which could safely carry the conductors when spaced some 300 yards apart, a distance which it was hoped might give the lines the same sort of catenary that one might see in a suspension bridge.

This initial concept has stood the test of time and the overall philosophy remains similar today. The main grid lines operated at that time at a voltage of 132 kV, and the early towers stood approximately 25 m high. An early example of a 132 kV transmission tower is shown in *Figure 1*. After the Second World War the whole picture of electricity supply changed rapidly with small power stations being shut down and fewer, larger generating units coming into service. To extend the grid at 132 kV would have proved impractical (four 132 kV lines would have been needed, at that time, to carry the same power as one 275 kV line), and the decision was taken to construct a new 275 kV 'supergrid'. In 1950 construction started with the lines and pylons designed so that they could be modified to operate at 400 kV at some future stage.

During the 1950s and 1960s a number of different designs of lattice towers were developed by major contractors employed by the CEGB to build the supergrid in England and Wales. The lattice steel tower solution was still seen as the preferred option and, in fact, remains the most cost effective design solution today. The design of these towers was based upon parameters laid down in Statutory Instruments, and while there were detail differences between the designs adopted by the various contractors, in essence the design approach remained the same.

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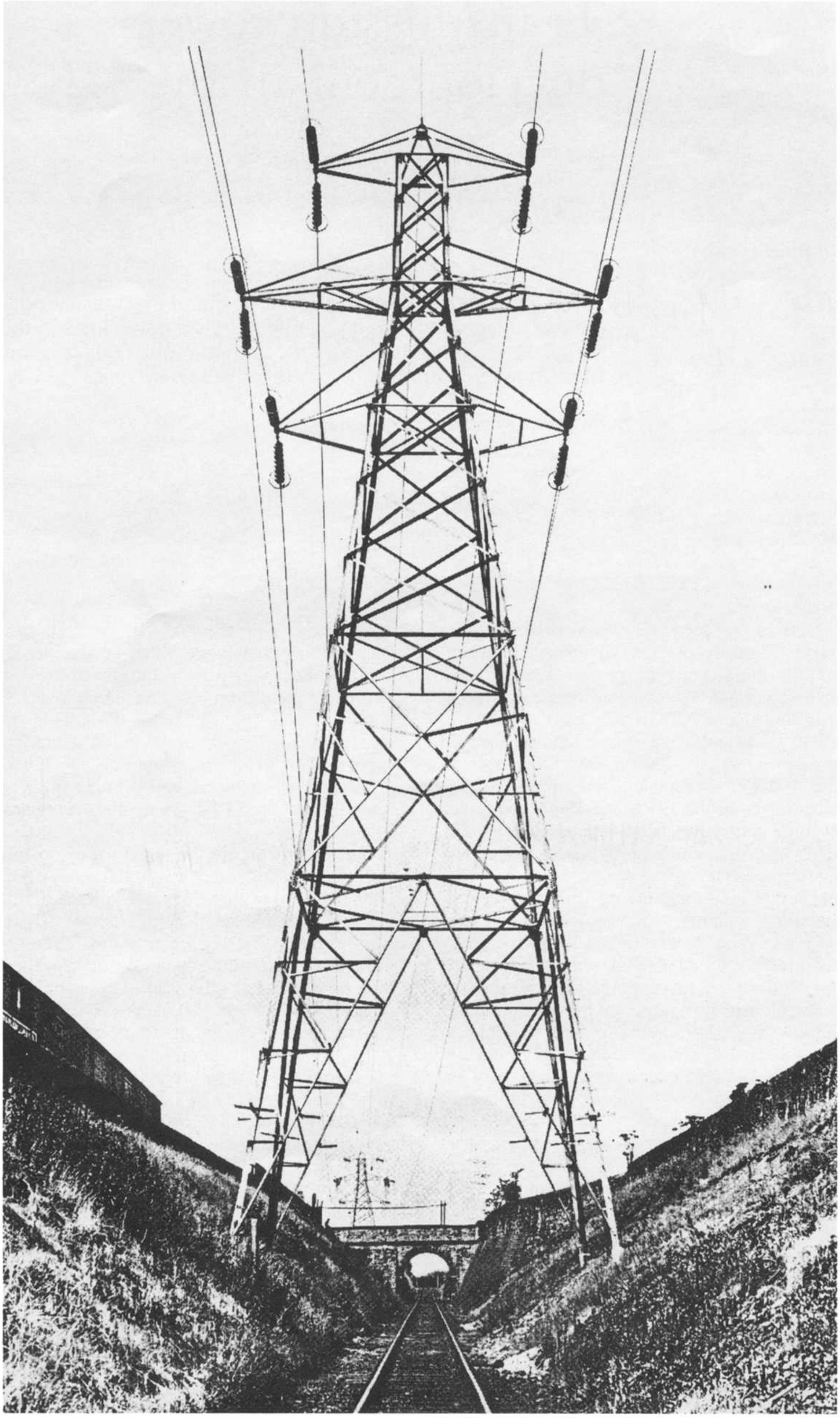

Figure 1 1932 grid line straddling a railway

The height of a tower is dependent upon such factors as ground clearance, sag of conductors and length of insulator (suspension tower). The profile of the tower needs to take account of the height and phase clearance of the conductors. In determining the main leg spacing the designer must consider the width and slope of the lower leg sections. If the base width is too small the legs will be heavily loaded and the foundations costly, if the width is too large bracing lengths and hence size will be increased. An optimum design will generally be achieved when the weight of legs and bracing is approximately the same.

There are four conventional patterns for bracing: *Figure 2* will serve to demonstrate the principles. At the very tip of a tower, if the loading is light, a simple zigzag will suffice. As the legs are widened slightly further apart it is convenient to use an X pattern with the diagonals pinned together where they intersect, so that the bracings are short and stiff enough to be effective in compression as well as in tension.

As the legs are moved further apart the length of the diagonal members increases and they become unstable in compression: the answer is to support them with secondary bracing between the diagonals and the legs, which opens up a square or 'diamond' within the tracery of the secondary bracing.

As the legs move yet further apart the diamond becomes larger and the bracing becomes less effective in steadying the legs. It is necessary to introduce a horizontal member to tie the legs together, which leads to a K brace – a figure K turned on its side so that the straight member of the K runs horizontally between the legs.

There are no precise stages in the development of a bracing pattern that dictate an exact point where it is necessary to change from a zigzag, to an X, to a diamond, to a K. It depends on the designer's choice of metal thickness and cross-section for individual leg and bracing members, but the change from one geometry to another as the tower width increases, predominates in lattice tower design, whoever and wherever the designer. The most elegant bracing solutions avoid too many changes in geometry, maintain a coherent pattern and maintain a logical progression up the tower.

Transmission towers in England and Wales are generally comprised of galvanized bolted angles erected piece small on site. There is a feeling among some

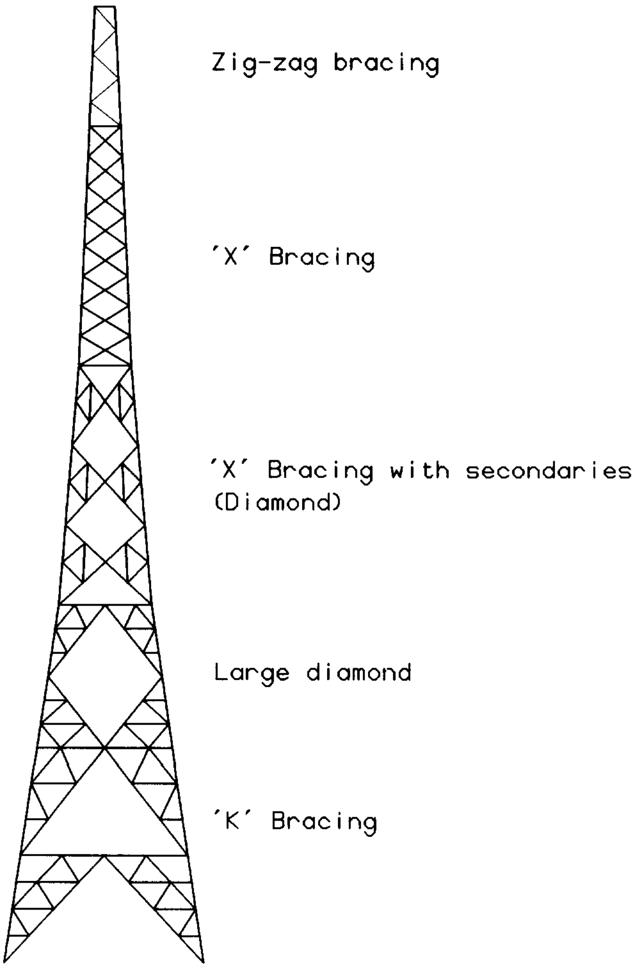

Figure 2 Bracing patterns

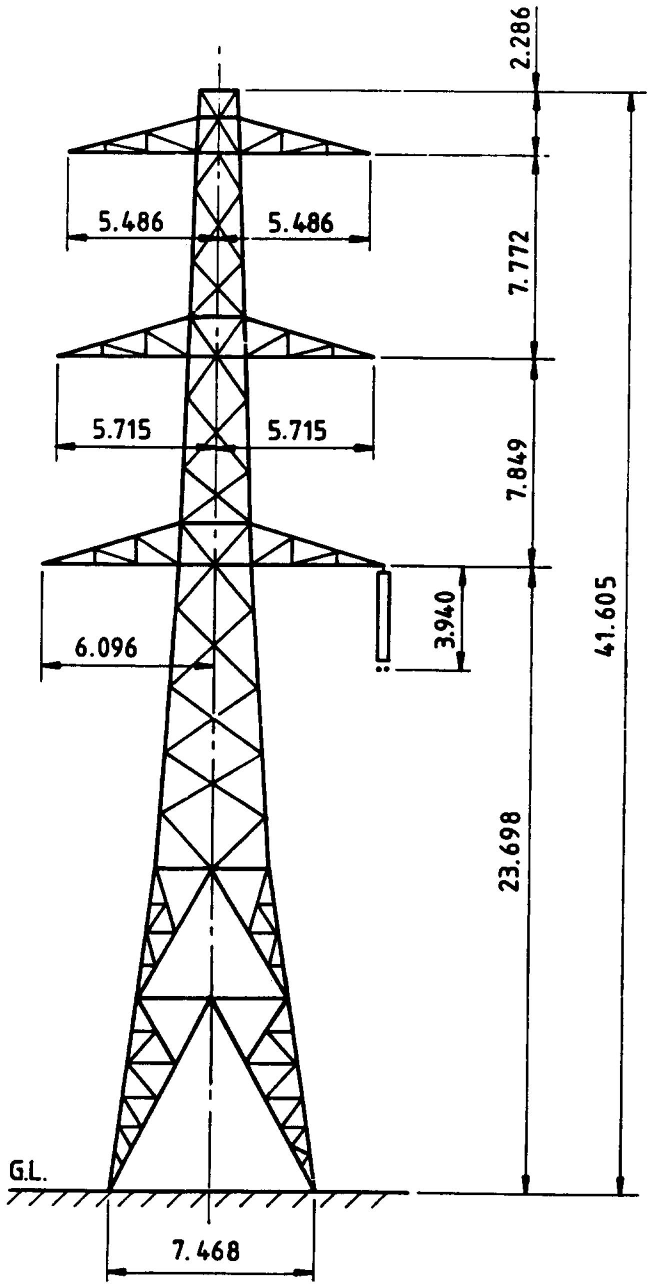

Figure 3 L2 D tower

viewers that tubular members produce a more elegant tower, because the reflective geometry of the surface makes them appear less intrusive and because tubes are stiffer than angles for the same section width and need less secondary bracing. However, they produce problems. It is relatively expensive to devise a bolted joint between tubes; the alternative of a welded joint is expensive because it takes longer to make and requires temporary staging to carry it out, and there are difficulties in the control of the quality of welding on a large number of towers on remote sites. Tubes also give rise to problems of inspection of any internal corrosion. Tubes may be appropriate on single one-off radio or television towers, however, they are less appropriate for a transmission line. The dynamic advantages of a tube (less wind resistance than the equivalent angle member) are also less important for a transmission tower where the predominant loading arises from the conductors.

It is not appropriate in a paper such as this to include much information on design parameters as these are covered in detail elsewhere.[1] The minimum requirements regarding wind and ice loading on the intact system of towers and conductors were specified in the regulations. Wind loading was taken at right angles to the line. These requirements tended to be more severe for higher voltage lines reflecting the increased reliability required of transmission lines compared to local distribution. A factor of safety of 2.5 against collapse was specified to cover meterological loading conditions. In addition, the towers were designed to withstand an out-of-balance longitudinal loading, resulting from broken conductors. The suspension tower was designed to accommodate one broken conductor or earthwire while the deviation and terminal towers were designed to accommodate three. A reduced factor of safety (1.5 or 1.3) was considered appropriate for this loading case.

The L2 double circuit suspension tower (D) (circa 1950) which carried three phases of twin 400 mm^2 ACSR (steel reinforced aluminium conductors) conductors per circuit is shown in *Figure 3*. The standard tower is 41.6 m high, 7.5 m wide at the base and has a maximum single span of 540 m with a maximum sum of adjacent spans of 800 m. A range of angle towers was developed for standard use and typically a 60° deviation tower (D60) is 43 m high and 10.8 m wide at the base. The design of the L2, being typical of the early designs, was optimized at 11.1 tons of steel for the suspension tower. The design of the

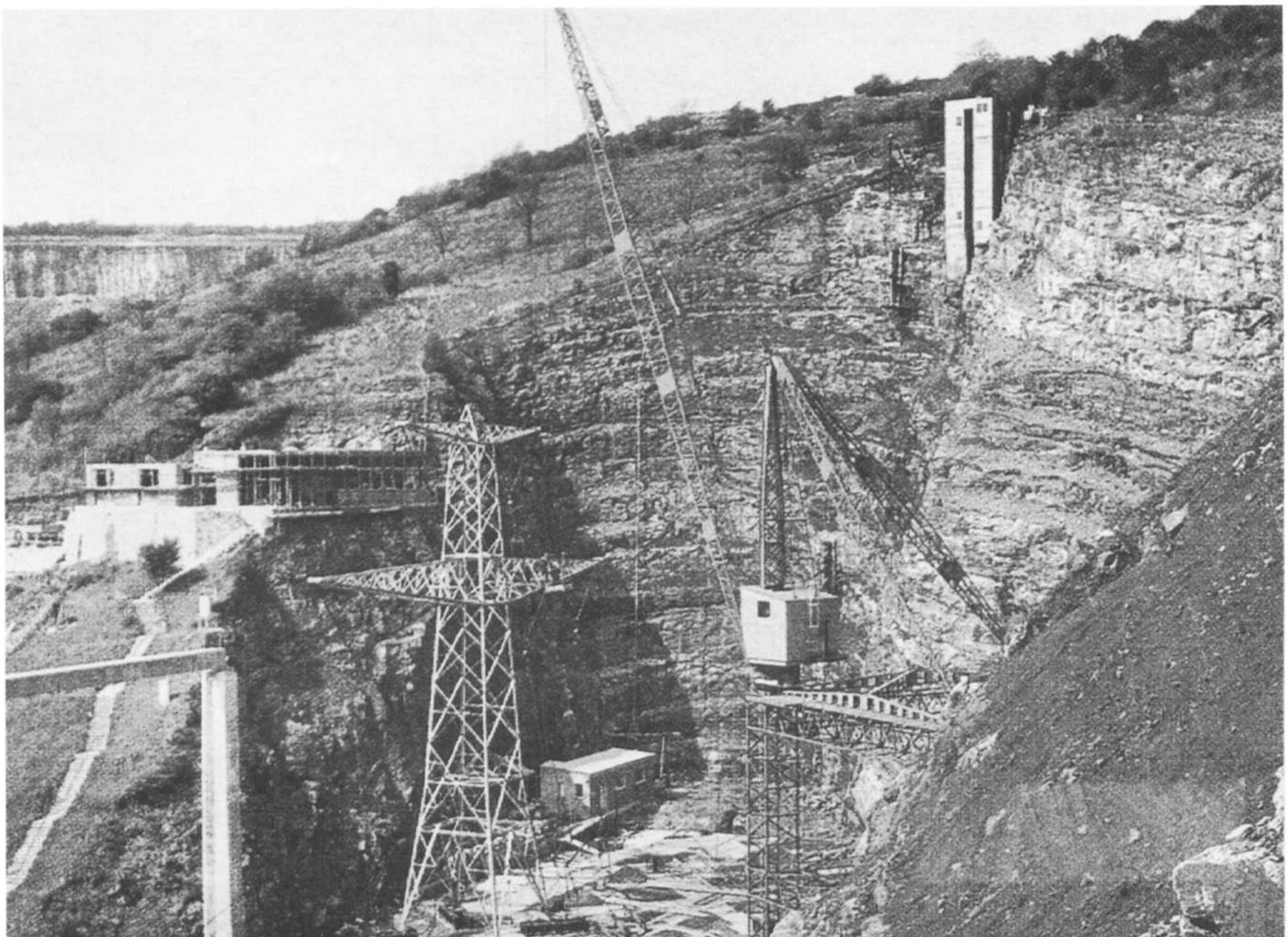

Figure 4 Tower under test at Cheddar

early towers had to be proved by test and a tower under test at the CEGB's testing station at Cheddar is shown in *Figure 4*.

By the early 1960s the demand for power from the grid had risen to the extent that a new design of lattice tower was commissioned by the CEGB to carry quad 400 mm^2 ACSR conductors in three phases per circuit. The L6 form of construction (*Figure 5*) became the basic structure for the overhead line development in the 1960s. A substantially larger structure than its L2 predecessor, it was developed to accommodate the same climatic loading conditions, although the design loads imparted to the lattice structure from the broken conductors had doubled.

Initially four separate detailed designs of the L6 tower were in existence but these were later rationalized into one new metric design when metric replaced the old imperial measures in the UK. The maximum span of the L6 suspension tower was still 540 m with the maximum sum of adjacent spans being limited to 800 m. The L6 suspension tower weighed 23.2 tonnes.

In the 1970s with the advent of computer technology, and the availability of increasingly more test data, designs became more sophisticated and designers throughout the world pooled expertise to produce strength codes. In addition a major breakthrough in conductor technology produced the new all aluminium alloy conductor which was utilized by the CEGB on the most modern design of lattice tower in the late 1970s. This L12 construction carries twin 700 mm^2 AAAC conductors per phase, the resultant reduction in loading allowing the designer the flexibility to produce what is considered to be the most elegant lattice tower of its type to date as shown in *Figure 6*. With a total weight of 15.8 tonnes the electrical and structural engineers had combined to reduce the weight of steel in the towers by

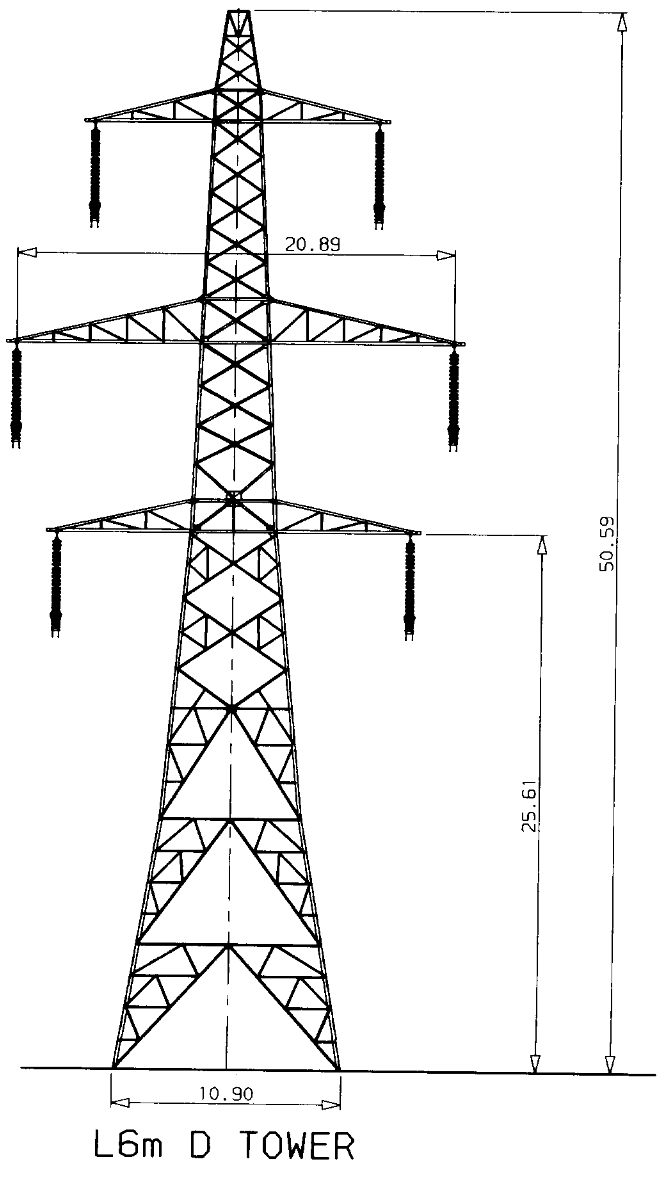

Figure 5 L6m D tower

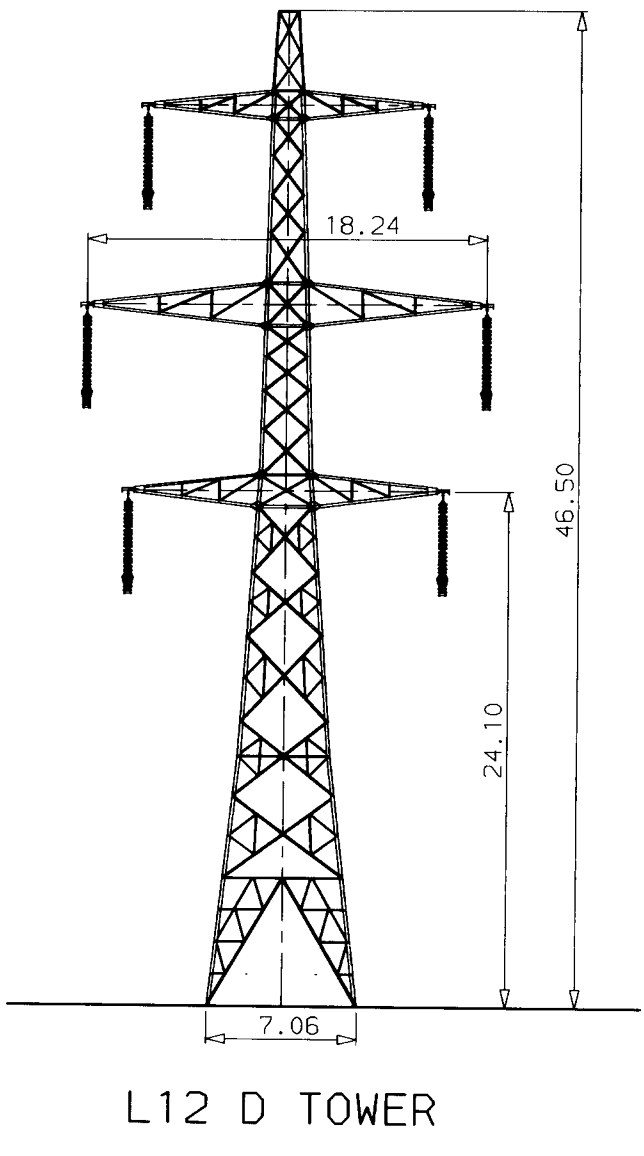

Figure 6 L12 D tower

one third, whilst still carrying almost equivalent electrical power.

Current regulations

The old UK Department of Energy regulations were replaced in 1987 by the simple statement that 'transmission towers should be fit for the purpose intended'. Guidance on climatic loading conditions is now available for the designer in BS 8100: Code of Practice for Loading Lattice Towers and Masts which was published in 1986. This standard which is based upon a probabilistic 50-year return period for ice and wind loading now makes it possible to vary the designs of towers in different parts of the UK and at varying altitudes. The complex steelwork detailing requirements of the lattice tower make it unlikely that it will be cost effective to make NGC designs site specific unless the total tonnage of steelwork required is very substantial. The designer does, however, have the flexibility to vary the spans in different parts of the country.

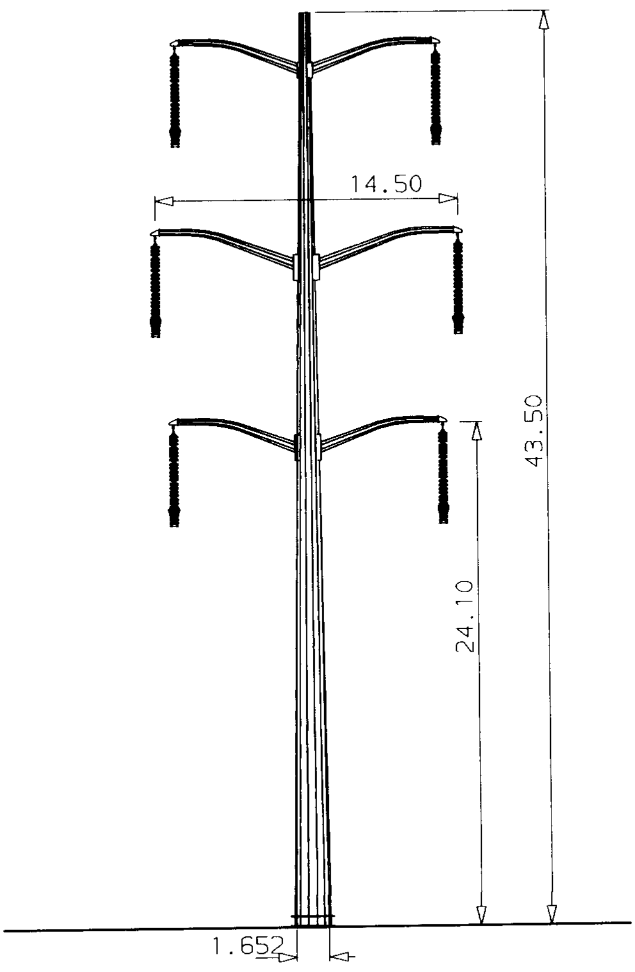

Figure 7 Folded plate tower

Alternative tower designs in the UK

Whilst it still remains as true today as it was in the 1920s and 1930s that the lattice tower is likely to produce the most cost effective structural solution to overhead lines, the National Grid Company has been investigating alternatives which may be considered to have less visual impact by way of form or reduced height. None of the work which has made up the current study can be considered to be novel or innovative simply bridging the gap between the 1970s and 1990s, NGC has studied folded plate steel poles, (used extensively in Europe and North America but only to a limited extent at 132 kV in the UK), gantries and a new low height lattice tower. All these new designs have been based on the current loading requirements and the L12 specification, and are shown diagrammatically in *Figures 7–9*. Probably the most attractive of the alternative designs is the folded plate pole which is fabricated from steel plate pressed and welded into a tapered tube. The diameter of the base is obviously dependent upon the thickness of the plate, however, in the design studies undertaken to date the diameter has been optimized at 1.65 m for a suspension tower with a span of 360 m. The weight of the pole and hence the cost is, however, significantly greater that its lattice equivalent (23.7 tonnes).

NGC's advisors and designers have concluded that the L12 lattice and folded plate pole are, in general, preferred to the low height structures. When seen from afar the pole is significantly less intrusive than any of the other towers because of its slenderness, although it may appear large and clumsy when seen at close range, when its form is replaced by its bulk. Where there is an opportunity to screen the towers from an important viewpoint, the lower height towers can be used to advantage. The disadvantage is that there will be an increase in impact wherever the line is visible, although there may be an overwhelming need for a low height structure to keep within height restrictions for low flying aircraft.

The alternatives are presented in photomontage form in *Figures 10–14*. Construction impact, as well as visual impact, must be considered when assessing the alternatives.

Lattice structures are erected on site using a climbing derrick and the foundations are, in the main, fairly simple to construct. The pole requires substantial cranage for erection and the foundations are generally formed from large diameter bored piles. Depending upon accessibility, the need for temporary tracking may be a fairly significant item for pole construction.

The costs presented below are expressed as a ratio of overall line costs compared to the standard L12. Actual costs will depend on several factors: the site conditions, the geographical location and accessibility, and the size and timing of contracts. It must also be noted that no major contracts have been placed by NGC for several years and there is little construction experience in the UK of the alternative types of tower. As an indication, the order of total cost of an overhead line at the present time is £500 000 per kilometer.

L12 lattice tower (360 m span)	1.0
L12 lattice low height (310 m span)	1.2
Folded plate poles (360 m span)	2.0
Gantries (300 m span)	1.9

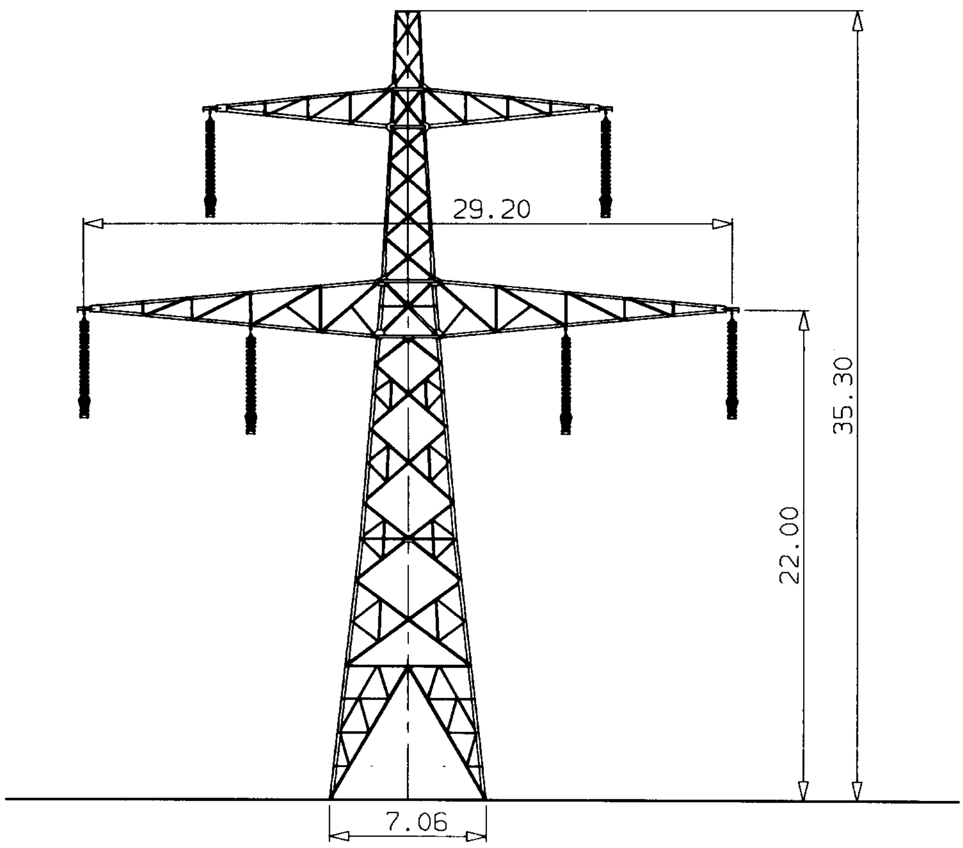

Figure 8 L12 LD tower

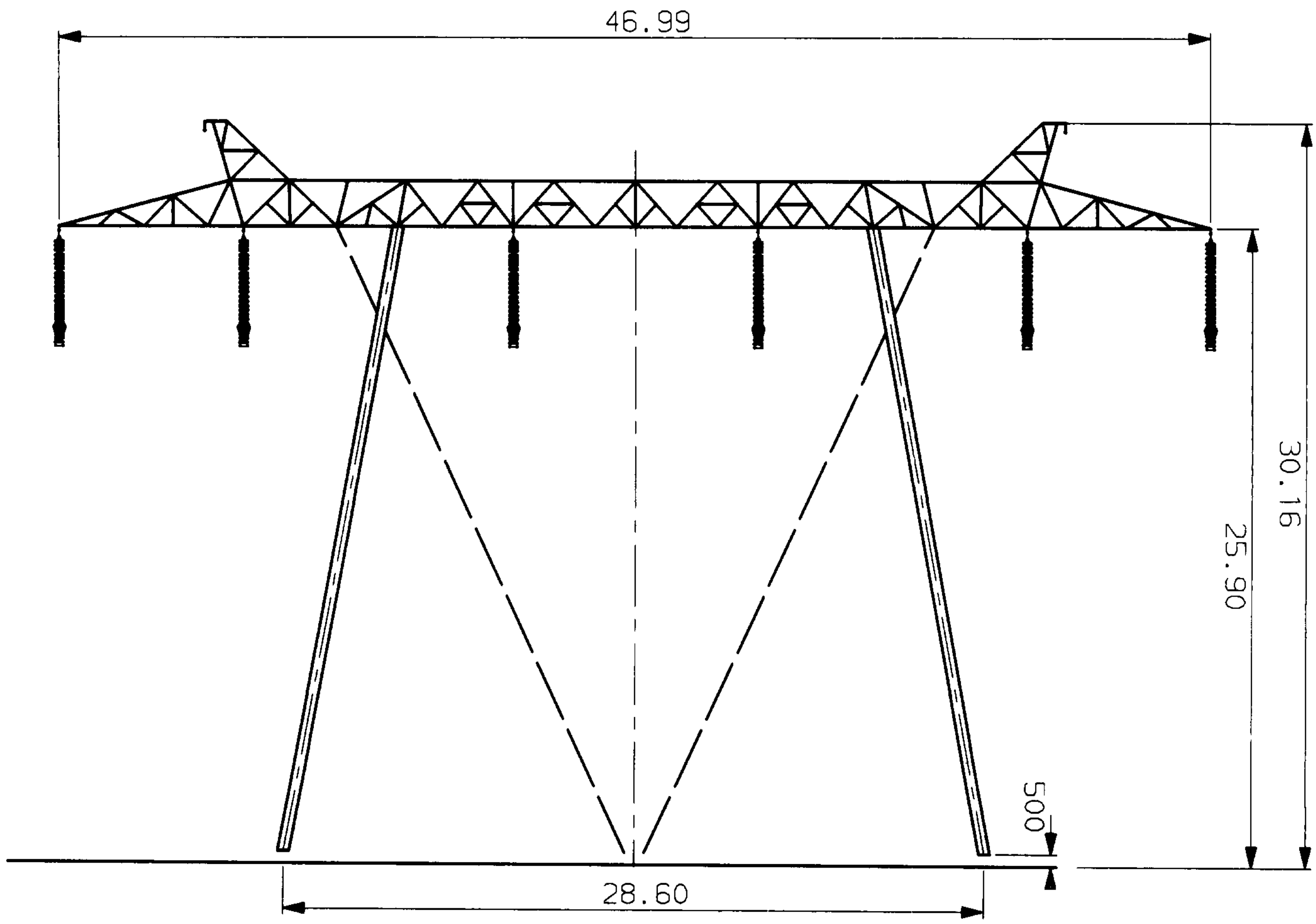

Figure 9 Low height gantry tower

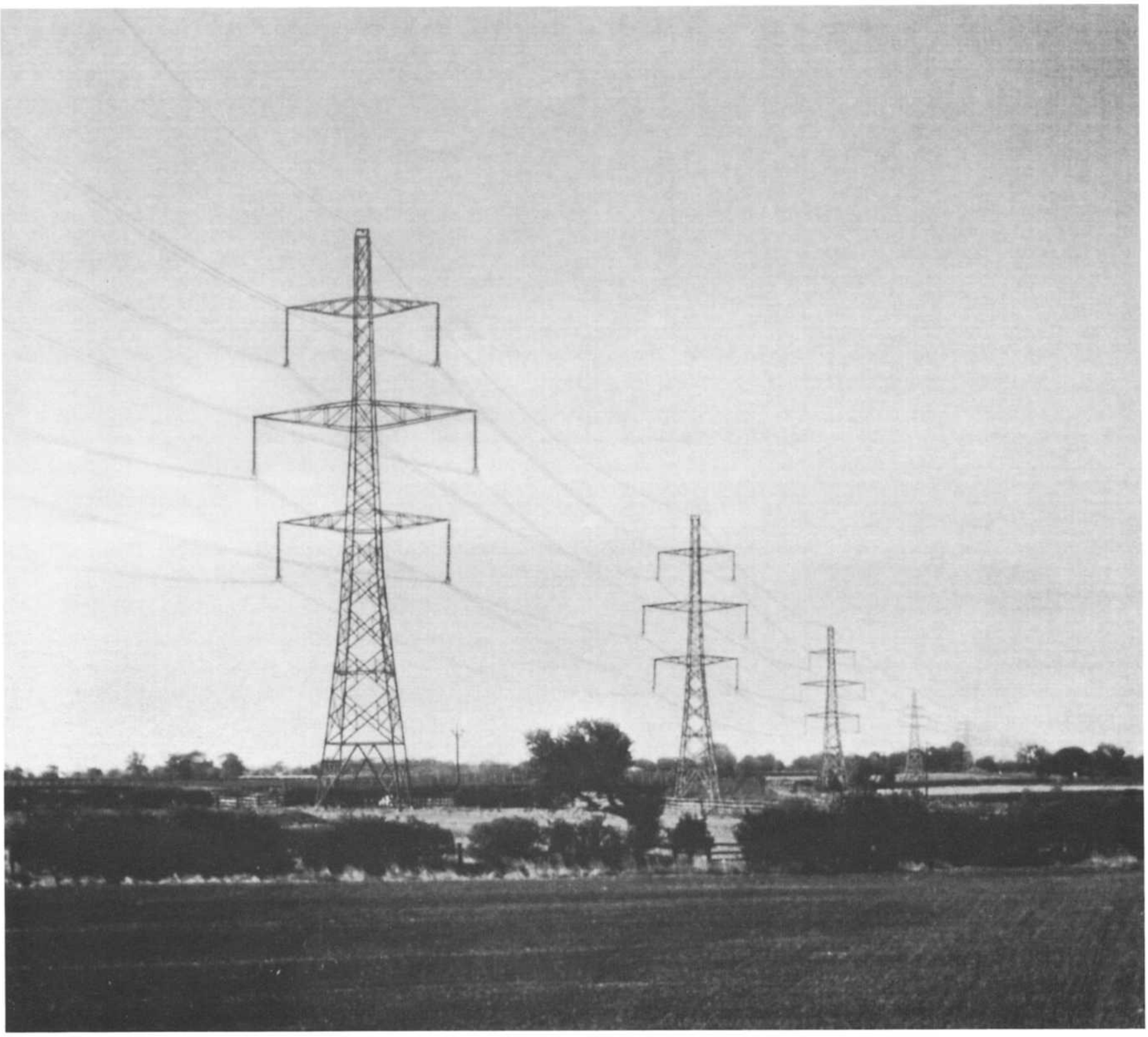

Figure 10 Generic tower types, L12 towers

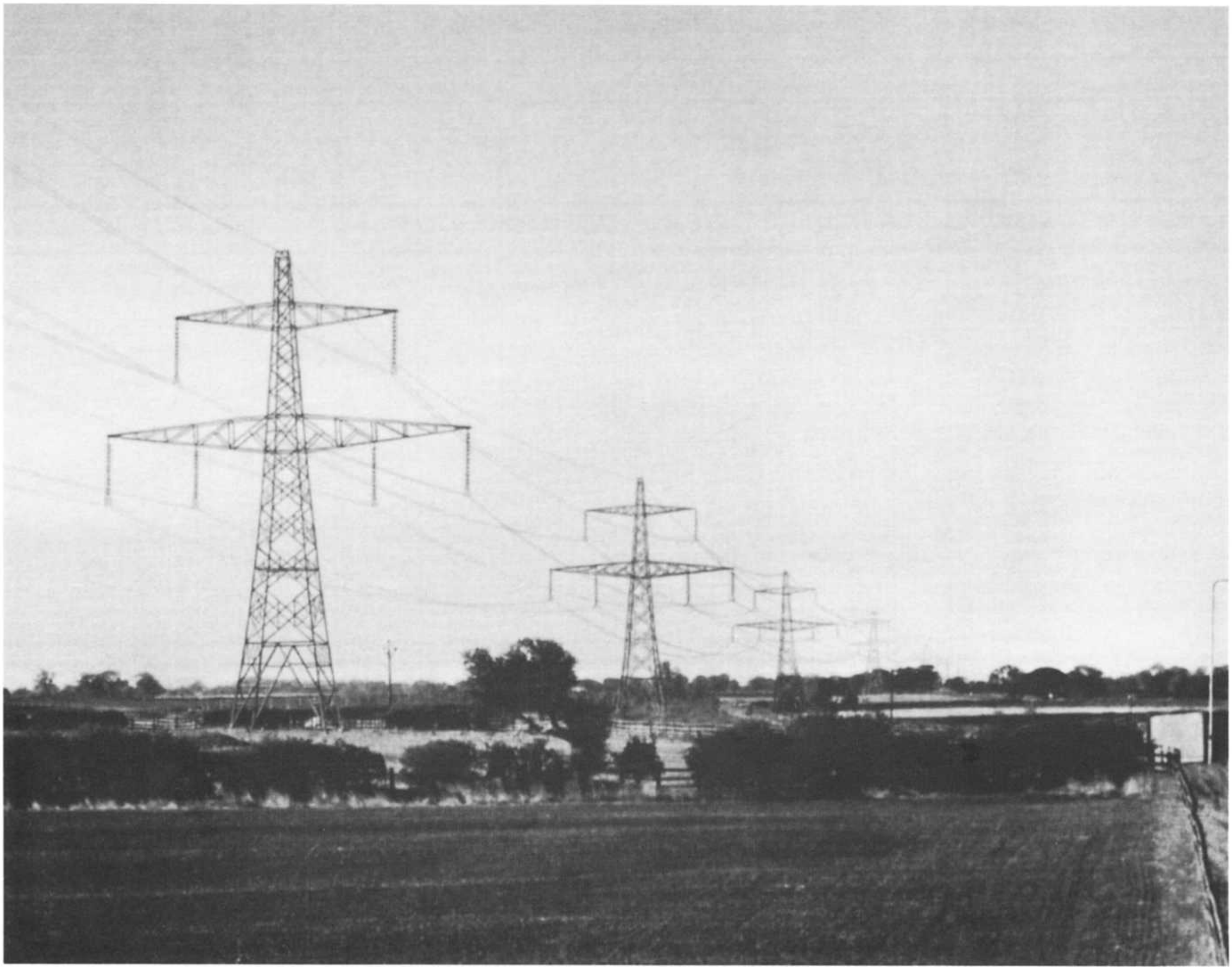

Figure 11 Generic tower types, low height L12 towers

Figure 12 Generic tower types, folded plate pole (gull wing arms)

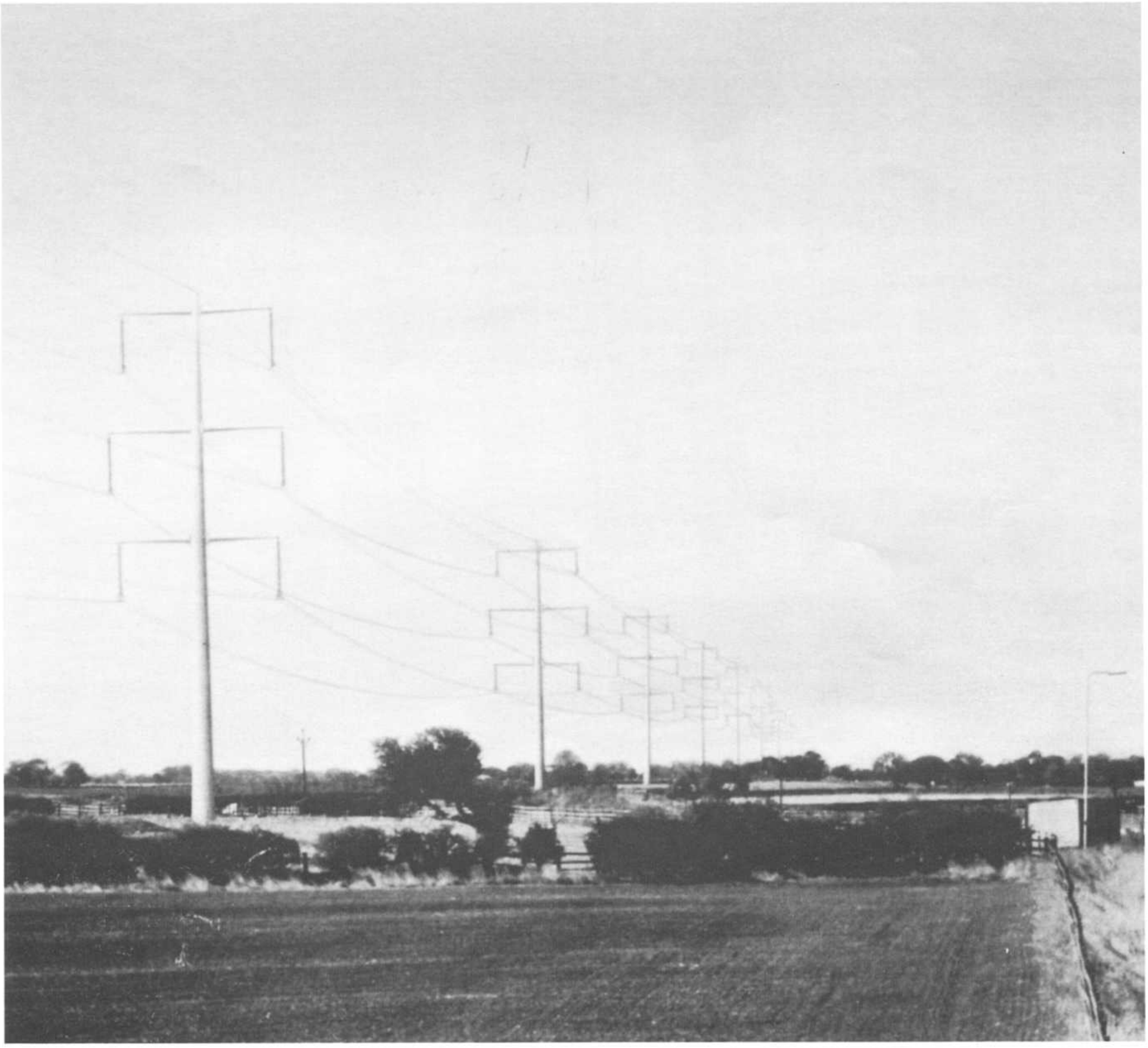

Figure 13 Generic tower types, folded plate pole (straight arms)

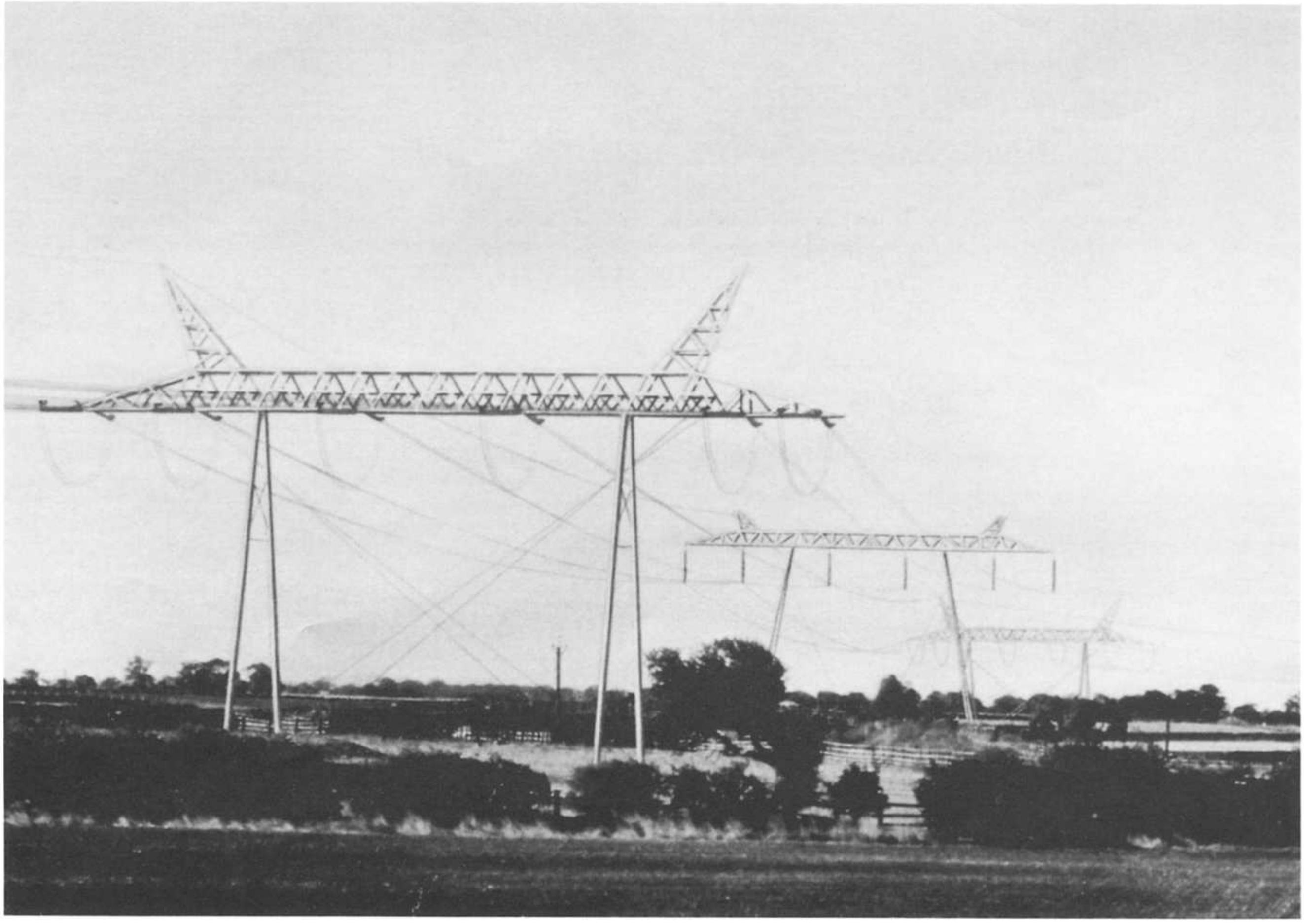

Figure 14 Generic tower types, L12 gantry towers (angle)

Conclusions

The lattice tower which has been the predominant feature of the overhead line network in the UK for over fifty years is still likely to be the NGC's preferred option on most new routes for some years to come, however, the NGC line designers and landscape advisors are being encouraged to consider the use of the alternative tower types in an effort to minimize visual impact. Studies of alternative tower concepts are ongoing.

References

1 Adam, J. F., Bradbury, J., Charman, W. R., Oraniski, G. and Vanner, M. J. Overhead Lines. Some Aspects of Design and Construction *Proc. IEE Part C* 1984, **131** (5), 149–187
2 BS 8100 Lattice towers and masts, Part 1, Code of practice for loading, British Standards Institution, London, 1986