Appendix A provides applications of AS/NZS 3008.1.1, and you should work through each example given to help you in gaining skills and knowledge in cable selection procedures.

Cable selection procedure using the standards

Suggested procedures for the selection of a cable for a particular application, using AS 3000 and AS/NZS 3008.1.1, are summarised in Figure 16.2.

16.5 Current-carrying capacity

Maximum-permissible cable temperatures allowed for insulated cables are listed in *Table 2.1* of AS 3000; *Table 1* of AS/NZS 3008.1.1 also is applicable. As can be seen from these tables, the determining factor is usually the type of cable insulation. For the same reason, if the cable is in contact with materials having lower temperature limits than its own insulation, a further reduction in operating temperature may be required (by reducing current-carrying capacity).

The amount of heat produced may be calculated thus:

$$H = I^2Rt,$$

where H = amount of heat produced in joules
I = cable current in amperes
R = resistance of cable in ohms
t = time for which current flows in seconds.

The resistance of a cable of given length will be determined by the conductor size and material. Replacing a cable with a similar cable that has a conductor of larger cross-sectional area will reduce the heat produced by a given current. Cables with copper conductors will produce less heat than similar cables with aluminium conductors of the same cross-sectional area due to the lower resistance of copper.

Installation conditions and external influences

As noted in section 16.2, the installation conditions and external influences that affect current-carrying capacity are:

- ambient temperature
- thermal insulation
- whether cables are enclosed or unenclosed
- grouping of cables
- direct sunlight
- varying loads.

Ambient temperature

For a given current, cable and time there will be a temperature rise, which, when added to the initial ambient

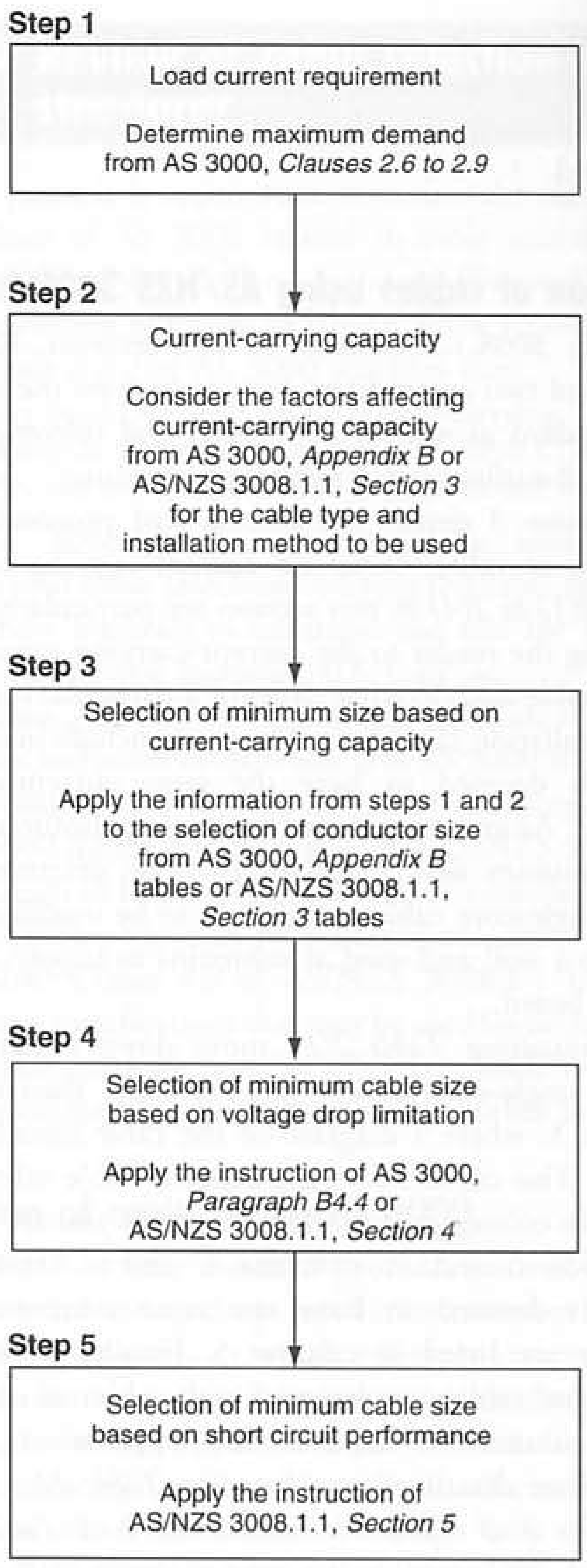


Fig. 16.2 *Steps for selecting a cable for a particular application, using AS 3000 and AS/NZS 3008.1.1*

temperature, produces the final operating temperature of the cable. The higher the ambient or initial temperature, the higher the final temperature, because the temperature rise is nearly a constant (for a given current) within the temperature ranges we are dealing with.

If ambient temperature is higher than the temperature that provides the basis for the current-carrying capacity of a cable, to maintain the cable within its temperature limits the current-carrying capacity of the cable must be less by an appropriate derating factor. If, on the other hand, the ambient operating temperature is lower than the specified ambient, the current rating may be increased.

The ambient temperature base, for the current-carrying capacities of AS 3000, *Appendix B* and for those of AS/NZS 3008.1.1, is 40°C for air and 25°C for soil temperature. In a heated concrete slab the ambient

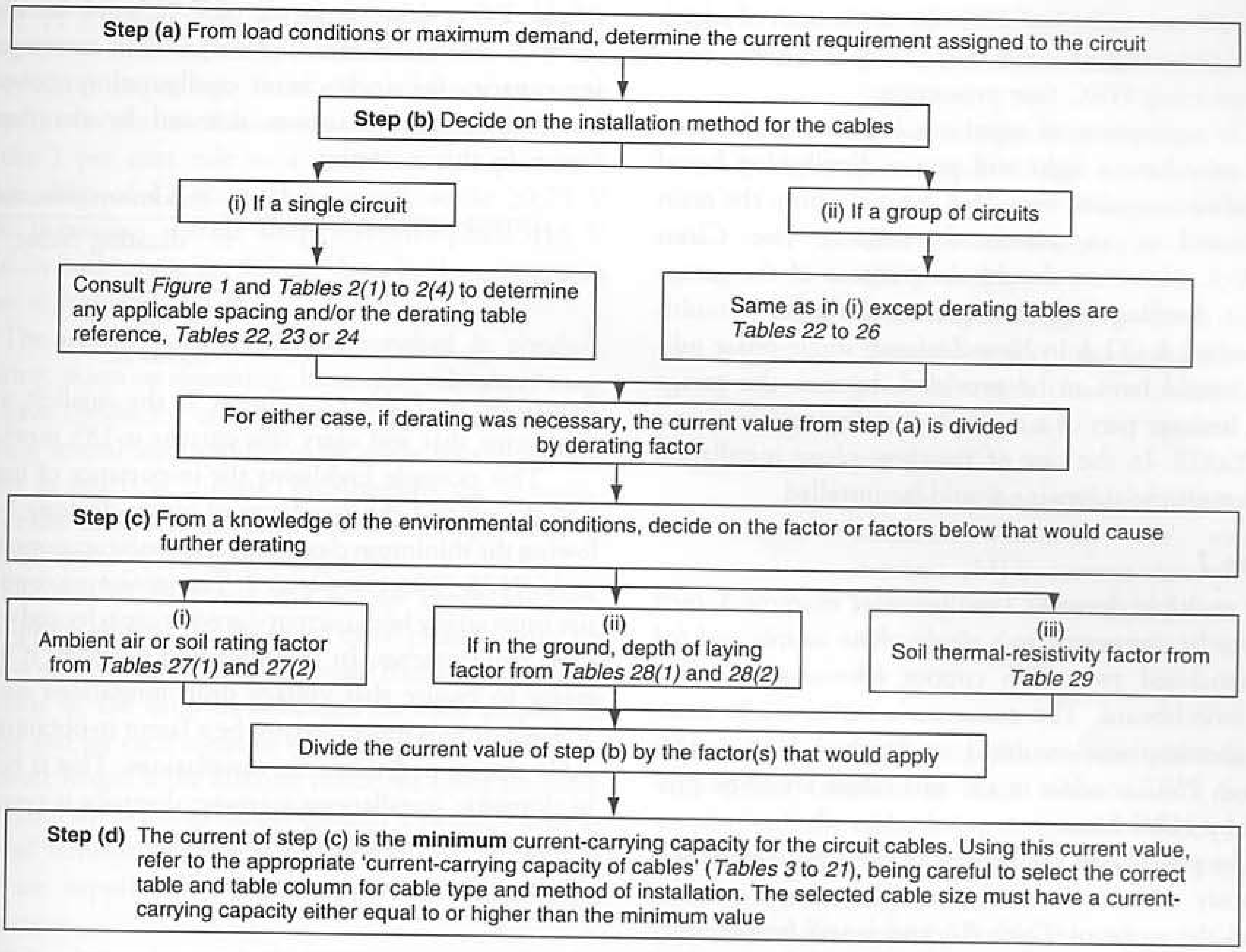


Fig. 16.3 *Determination of minimum cable size using AS 3000 and AS/NZS 3008.1.1*

16.6 Selection of minimum cable size based on current-carrying capacity

The current-carrying capacity of a cable must not be less than the maximum demand of the circuit that it supplies (AS 3000, *Clause 2.2.2.1*). The maximum demand, together with the previously mentioned factors affecting current-carrying capacity, is the basis for determining the minimum conductor size for a particular application. This is provided that voltage drop limitation and short circuit performance are satisfied.

The following examples will provide a guide to the selection of conductor sizes and should be studied in conjunction with the appropriate standard. These examples refer to and are extensions of the examples for calculating maximum demand in section 16.3 of this chapter.

Example 5

In the case of the single domestic dwelling of example 1 the maximum demand was calculated at 74.58 A. Note that *Clause 2.13.1(a)(i)* requires a single-phase consumer's mains to have a minimum current-carrying capacity of 63 A (32 A in New Zealand), and that the calculated maximum demand exceeds this value. The consumer's mains are to be V75 thermoplastic-sheathed (TPS) copper cables installed unenclosed in air, in accordance with AS 3000, *Paragraph B4.2.1*.

Assuming that protection is by HRC fuse (as would generally be the case with a consumer's mains), the minimum permissible conductor size is 16 mm², selected from *Table B2*, columns 1 and 15, or from columns 1 and 2 of *Table 3.1* of AS/NZS 3018. The current-carrying capacity of this cable under these conditions is 80 A. For this installation, some future addition could be made without increasing the size of the consumer's mains.

Example 6

The multiphase consumer's mains supplying the single domestic dwelling of example 2 are to be V75 insulated copper cable installed in polyvinyl chloride (PVC) conduit underground. The maximum demand for each phase was determined as 19 A, 24.3 A and 27.3 A respectively. AS 3000, *Clause 2.13.1(a)(ii)*, and AS/NZS 3018, *Clause 3.1*, require multiphase consumer's mains for domestic installations to have a minimum current-carrying capacity of 32 A per phase. As the consumer's mains are installed as a single circuit, the reference is *Table B2*, columns 1 and 18 of AS 3000 or to *Table* commencing at the consumer's terminals comprises a series of successive voltage drops, which must be added to obtain the total voltage drop as specified by *Clause 2.2.3.* Note that the assumed current loading for mains and submains is the maximum demand current.

Final subcircuit current loading is estimated in accordance with *Clause 2.9*, with various approaches for different circuit types and loads.

Clause 2.2.3 indicates that the value of current used for calculating voltage drop need not exceed the total of the connected load or, for final subcircuits, the current rating of the specified circuit-protective device. Hence, if the maximum current loading for a portion of a circuit is known, this is the figure used for calculating the voltage drop in **that section**.

For a mixed three-phase and single-phase load, it is usual to obtain the voltage drop in each line conductor separately and add:

$$\text{Total } Vd = \frac{Vd \text{ due to three-phase load}}{\sqrt{3}} + Vd \text{ due to single-phase load.}$$

With a two-phase three-wire supply, that is, two phases and neutral, taken from a standard 120° three-phase earthed-neutral system, the assigned table values for *Vc* in mV/Am may be multiplied by 0.75 for use in the voltage drop calculation.

If supply is single-phase three-wire, such as the single-wire earth-return (SWER) system in rural areas, with two actives at 180° and the neutral from an earthed centre tap, then the assigned table values of *Vc* in mV/Am may be multiplied by 0.5.

The tables of *Appendix B* show single- and three-phase voltage drop values, but the following factors may be used for conversion where both values are not known:

single-phase to three-phase
0.866 × single-phase value;
three-phase to single-phase
1.555 × three-phase value.

Excessive voltage drop

Now that you have developed your skills in calculating voltage drop in the various circuits of an installation, you should turn your attention to methods that might be adopted to avoid excessive voltage drop in practice. Example 15 demonstrates.

Example 15

Figure 16.5 illustrates the particulars of an installation in which the total voltage drop from the commencement of the consumer's mains to a 3.6 kW air conditioner exceeds the permissible value. HRC fuse protection is used for all circuits.

The overall voltage drop of 13.18 V is 1.18 V above that permitted; the main and submain voltage drops are acceptable. The most practical solution here would be to wire the final subcircuit in 2.5 mm² cable with a *Vc* of 18 mV/Am, thus reducing the subcircuit voltage drop to

$$\frac{18 \times 12 \times 15}{1000} = 3.24 \text{ V}$$

and the overall voltage drop to 11.2 V, which is acceptable.

Voltage drop in an ac circuit is the product of current and impedance; that is,

$$V = IZ.$$

If voltage drop is excessive, the **impedance or current must be reduced** to lower it. Usually the load current cannot be altered, and so impedance must be reduced.

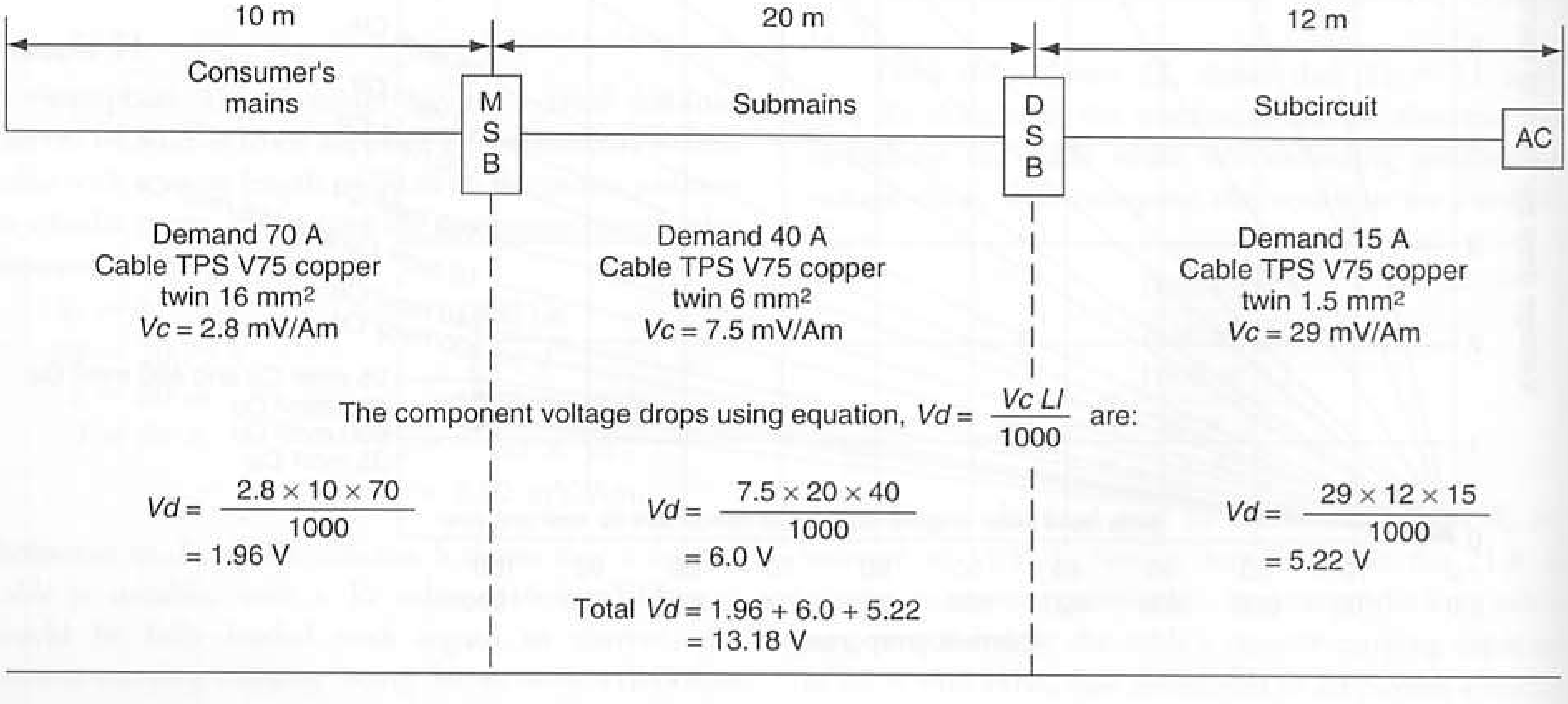


Fig. 16.5 *Progressive voltage drop (example 15)*

Table 16.7 *Example 3 calculation*

Load	*Load group*	*Calculation*	*Demand current (A)* L1 (red)	L2 (white)	L3 (blue)
Red and white phases 5 units each					
Lights	A	2 to 5 units allow 6 A	6	6	
GPOs	B(i)	2 to 5 units allow 10 A + 5 A per unit 10 + (5 × 5) = 35 A	35	35	
Range	C	2 to 5 units allow 15 A*	15	15	
Water heater	F(ii)	2 to 5 units allow 6 A per unit 6 × 5 = 30 A**	30	30	
Blue phase 6 units					
Lights	A	6 to 20 units allow 5 A + 0.25 A per unit 5 + (0.25 × 6) = 6.5 A			6.5
GPOs	B(i)	6 to 20 units allow 15 A + 3.75 A per unit 15 + (3.75 × 6) = 37.5 A			37.5
Range	C	6 to 20 units allow 2.8 A per unit 2.8 × 6 = 16.8 A			16.8
Water heater	F(ii)	6 to 20 units allow 6 A per unit 6 × 6 = 36 A			36
		Total demand current for units	86	86	96.8
Community services					
Lights on white phase	H	Full-load current (6 × 75) + (4 × 150) = 1050 W $I = \frac{1050}{240} = 4.4$ A		4.4	
4 GPOs on red phase	I	2 to 5 units allow 2 A per point 2 × 4 = 8 A	8		
3 GPOs on white phase	I	2 to 5 units allow 2 A per point 2 × 3 = 6 A		6	
		Maximum demand per phase Select highest phase, i.e. 96.8 A	94	96.4	96.8

* Note that 15 A is **total** demand, not 15 A per unit.
** See footnotes to *Table 2.3* re classification.

not the only consideration in this case, as *Clause 2.14.2* requires that a cable having a current-carrying capacity of not less than 63 A be installed for single-phase sub-mains supplying a domestic installation within a multiple installation.

Non-domestic demand

It may be seen that the maximum demand assessments considered so far follow a common pattern, and a broadly similar approach may be used for a non-domestic installation such as a factory or residential institution. *Clause 2.6.3* and *Table 2.4*, together with *Clause 2.6.4* (where welding machines are installed), should be used to determine the various diversity factors to be applied to the load groups.

Example 4

A small factory load connected to a 415 V three-phase supply has been grouped and a preliminary balance carried out to divide the single-phase loads as evenly as possible over the three phases for balance. Each phase load is now to be separately assessed for maximum demand purposes. The energy distributor for the area in which the factory is situated will permit 500 W of uncorrected fluorescent lighting per phase.

The following is the listed equipment on one phase of the three-phase 415/240 V supply to the factory:

- 10 × single 36 W fluorescent luminaires (with lagging ballast)
- 5 × twin 36 W fluorescent luminaires (non-stroboscopic with a leading and lagging ballast)
- 8 × 100 W incandescent lamps

2 × 500 W floodlights
20 × GPOs
2 × 15 A socket outlets
1 × 8 kW storage heater (continuous element).

This phase also has connected to it one supply line to four arc welders (415 V single-phase) with primary currents of 20, 20, 16 and 14 A respectively.

In addition, the following three-phase motors are installed:

6 × three-phase motors, rated line current 15 A each
3 × three-phase motors, rated line current 7.5 A each
3 × three-phase motors, rated line current 5 A each.

By reference to *Table 2.4* of AS 3000, the maximum demand may be determined as shown in Table 16.8.

Each of the other two phases should be treated similarly to the phase above and the three separate phase demands should be checked, as in previous examples. This will ascertain whether any transfer of load between phases would lead to a better balance. Once a final demand figure has been determined, the highest single-phase demand is used to select cables and adequately rated control gear and protective devices.

Maximum demand of final subcircuits

The maximum demand for final subcircuits is usually the connected load, which may be determined as follows:

- It may be assessed or measured by the energy distributor (*Clause 2.9.2*).
- It may be taken as the setting of a sealed circuit breaker (*Clause 2.9.3*). In a domestic installation, however, this clause does not apply to a final subcircuit connected to a single appliance (see also note below Fig. 16.1 on page 102).
- It may be taken as less than the setting of the circuit breaker if the circuit breaker setting has been uprated (*Clause 2.9.3(ii)*).
- The ratings assigned to lamps and lighting tracks are those of *Table 2.3*, footnote (l).
- If the circuit supplies one appliance only, the demand is the full load current of the appliance (i.e. nameplate rating). The one exception is a range in a **domestic** installation, where the diversity allowed in *Clause 2.9.4.2* may be applied.
- For a circuit supplying more than one appliance or socket outlet the maximum demand is the total load or the rating of the circuit protection device, whichever is the lesser (*Clause 2.9.5*). The loading and number of points that may be connected to a final subcircuit must comply with *Clause 2.11* and are detailed in *Tables 2.5* and *2.6* for single-purpose circuits and *Tables 2.7* and *2.8* for mixed circuits.

The number of points for special lighting circuits, such as those supplying signs, stage lighting and outdoor light involving long cable runs, is limited only by the current-carrying capacity of the circuit cables (*Clause 2.12.3*). Although temporary lighting falls into this category, *Clause 2.12.3(d)* restricts the circuit load in these cases to 16 A. *Clause 2.11.1.4* prohibits the

Table 16.8 *Example 4 calculations*

Load	*Load group*	*Working*	*Demand (A)*	*Notes*
Lighting*	A	Incandescent $\frac{(8 \times 100) + (2 \times 500)}{240} = 7.5$ Fluorescent $(10 \times 0.43) + (5 \times 0.38) = 6.2$	13.7	Refer to Table 16.2 on page 98 for fluorescent current values
GPOs 20 × 10 A	B(i)	$\frac{1000 + (19 \times 750)}{240}$	63.54	Load group B(ii) diversity would apply if air conditioning or cooling and/or heating were permanently installed
Socket outlets 2 × 15 A	B(iii)	$15 + (15 \times 0.75)$	26.25	
Water heater	G	$\frac{8000 \times 1}{240}$	33.33	Note the diversity with regard to controlled water heaters (load group G)
Motors 6 × 15 A 3 × 7.5 A 3 × 5.0 A	D	$15 + (15 \times 0.75) + \frac{(4 \times 15) + (3 \times 7.5) + (3 \times 5)}{2}$	75.0	
Welders 2 × 20 A 1 × 16 A 1 × 14 A	H *Clause 2.6.4.2*	$(2 \times 20) + (16 \times 0.85) + (14 \times 0.70)$	63.4	A different diversity is applicable to resistance welders (e.g. seam or spot welders)
Maximum demand for the phase			275.22	

* Where an energy distributor has a separate tariff, it may prefer the lighting to be connected on one phase for economy in metering, unless lighting forms a major part of the load.

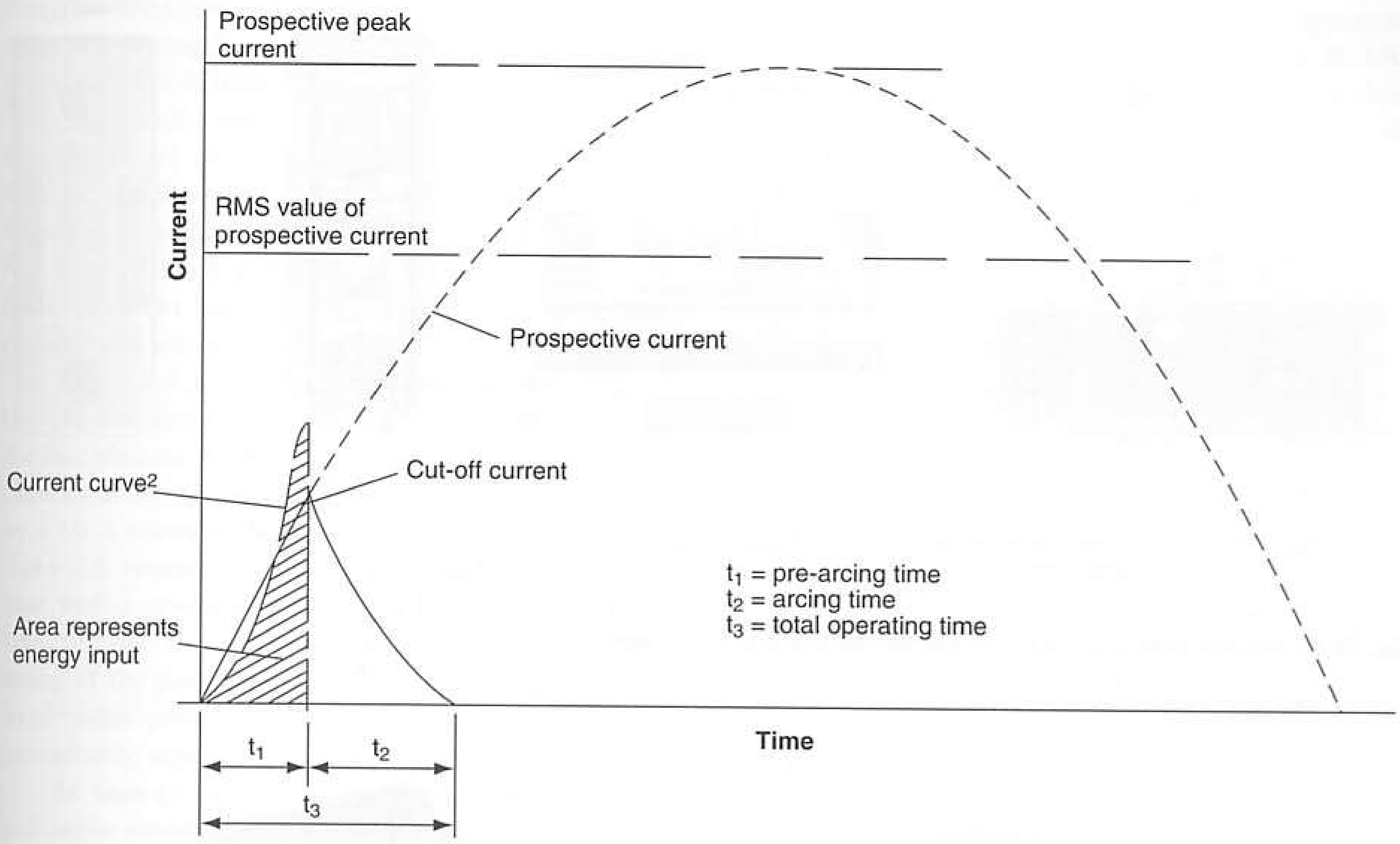


Fig. 13.7 *Illustrating how an HRC fuse will interrupt a circuit well before the peak value of prospective short-circuit current is reached*

Category of duty: The category into which the fuse is classified according to its fault-handling ability; that is, the value of the prospective current in the circuit. Categories A1 and A2 relate to prospective currents of 1.0 kA and 4.0 kA, while categories AC3, AC4, AC5, and AC80 cover the range of 16.5 kA, 33 kA, 46/50 kA and 80 kA (see Table 13.3). For industrial use, AS 2005 *Part 2* specifies that 'breaking capacity for fuses having rated voltage of 415 V ac and above shall not be less than 50 kA. For dc no value is specified'.

Table 13.3 *Category of duty for fuses*

Category of duty	Prospective fault current (kA)
A1	1.0
A2	4.0
AC3	16.5
AC4	33.0
AC5	46/50
AC80	80

Types of fuses

There are two basic fuse types:

- the commonly used and moderately priced semi-enclosed type, which is rewirable and used for relatively low current ratings and low category of duty; and
- the more expensive cartridge type, including the modern HRC fuse.

Figure 13.8 shows a typical semi-enclosed fuse, while Figure 13.9 illustrates a typical HRC fuse of relatively low current rating.

The semi-enclosed rewirable fuse

In AS 3135 this fuse is described as 'a fuse in which the element is neither in free air nor totally enclosed, apart from an external containing case'. This type, due to its design, lacks the capacity to deal with heavy fault currents. In general, the range is up to 100 A within category of duty A1 or A2, having 1.0 kA or 4.0 kA rupturing capacities, but intermediate categories are permitted. Its use is common in existing domestic installations, on distribution boards, or where prospective currents are within the limits of the device. It should be noted that a new standard, AS/NZS 3018—1997 *Electrical Installations—Domestic Installations*, published in April 1997, specifies circuit breakers for the protection of circuits in single domestic premises (see Chapter 16).

One disadvantage of the semi-enclosed fuse is that its characteristics may change, and in practice do change, in service and when fuse elements are replaced. Another disadvantage is its low breaking capacity. With these points in mind, it is of prime importance that the fuse carrier always be rewired with an element (fuse wire) of the correct rating.

Clause 2.4.3.2 of AS 3000 specifies that the rating must not be higher than 0.8 times the current-carrying capacity of the conductor that it protects, and it is the responsibility of the person replacing the fuse to ensure

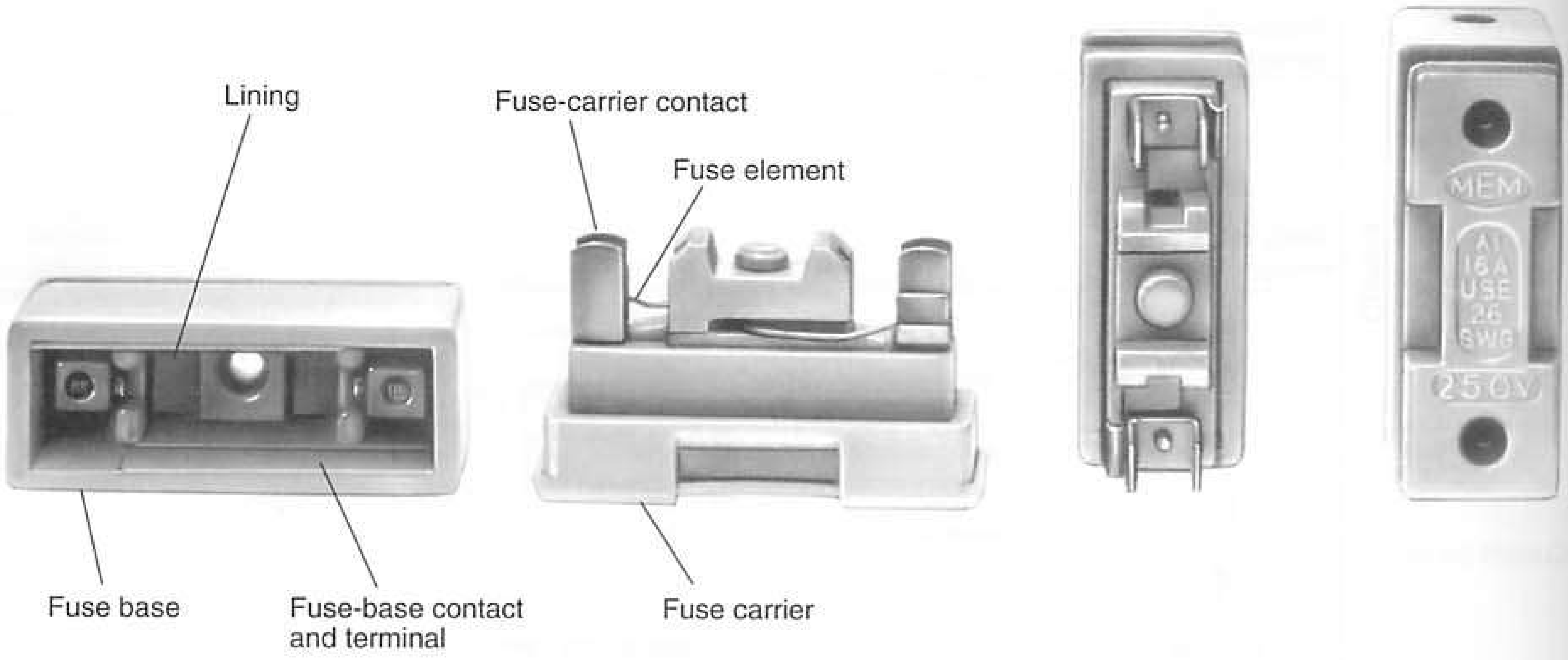


Fig. 13.8 *Component parts of a typical semi-enclosed rewirable fuse* BELL MEM

Fig. 13.9 *HRC fuse assembly*

capacity). An example would be a 50 A tee-off on a 400 A rising main feeder (see Fig. 13.14).

There are certain locations in an installation where the mounting of a fuse would introduce a hazard (e.g. at the back of a switchboard). *Clause 2.23.4.4(b)* prohibits this position except for fuses protecting control and instrument circuits or for special-type fuses being used as 'current limiters'. Other prohibited and restricted locations are listed in *Clauses 4.5.2.2* and *4.5.2.3,* and these should be studied, together with *Clause 4.5.2.1,* which requires that a fuse be located and installed in a way that will facilitate the easy withdrawal or replacement of the fuse carrier.

Where a fuse is located within equipment, its location within that equipment should be clearly shown in some appropriate manner. *Clause 2.23.4.4(a)* 'Grouping' requires that all fuses protecting conductors of any one circuit be mounted in a similar manner and grouped in such a way as to indicate their relationship. Too often an electrician's time is wasted in locating a particular fuse, due to poor layout. This aspect is dealt with in Chapter 17 also.

13.5 Circuit breaker protection

In common with the fuse, the primary function of a circuit breaker is protection, although it is usually provided with a switching facility. It is widely used to provide protection in its own right in place of a fuse, but may be used in conjunction with fuses, depending on the service duty required.

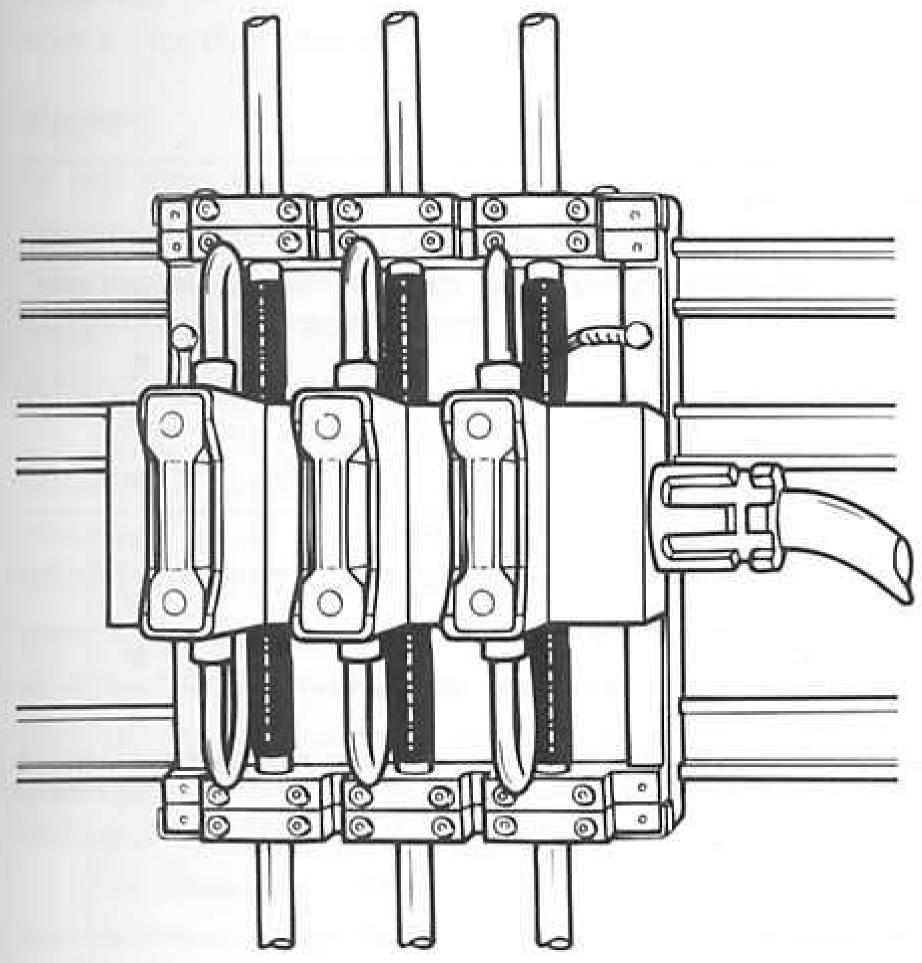


Fig. 13.14 *Fuses installed to protect cables teeing-off vertical mains in a multistoreyed building* MM CABLES PYROTENAX

The terms 'circuit breaker' and 'contactor' are sometimes confused or loosely applied. Both devices are switches in the broad sense (usually electrically operated); but if they are specifically designed to open **automatically** due to a predetermined condition of overcurrent or undervoltage they are classed as 'circuit breakers'. Refer to *Clause 0.5.26.*

Comparison of fuses and circuit breakers

Circuit breaker applications are more diverse than those of fuses, the range extending from the miniature circuit breaker (MCB) typical of those on a lighting circuit to circuit breakers with MVA ratings in power houses. There are earth leakage types (residual current devices, RCDs), those operated by inverse current, and many others. The practising electrician's interest lies, however, with those used for the protection of general wiring in domestic, commercial and industrial situations. A common classification for this type is moulded-case circuit breakers (MCCB), and to convey some appreciation of ratings the Cutler-Hammer Thermal Magnetic MCCB range is shown in Table 13.4(a) and (b).

The major operating difference between a fuse and a circuit breaker lies in the fact that, whereas the fuse element is a fusible and removable link in a circuit, the circuit breaker is both a switch and a protective device.

Restoration of supply after fault operation in the case of a fuse requires the replacement of the fuse element with one of similar rating and characteristics, whereas in the case of a circuit breaker the circuit breaker may simply be reclosed to restore supply. This may be done manually, automatically or by remote control. This last feature of convenience is the prime reason for its adoption in some circuits in preference to a fuse.

An interesting type of MCB that may replace a fuse in the conventional fuse base under certain conditions can be seen in Figure 16.1, Chapter 16.

The rewirable fuse suffers from the disadvantage that the incorrect fuse-element rating may be fitted, whereas most circuit breakers are sealed and are virtually 'tamperproof'. With higher ratings and open-type circuit breakers, it is usually possible to adjust overload and time-lag settings.

Another disadvantage of fuses is that on three-phase circuits they may open on only one or two of the phases, leaving the others live. On many circuits this creates hazards of feedback and single phasing of motors. The circuit breaker, on the other hand, trips on all phases simultaneously.

Classification of circuit breakers

As with fuses, the protective functions of a circuit breaker are protection against overload and short circuit.

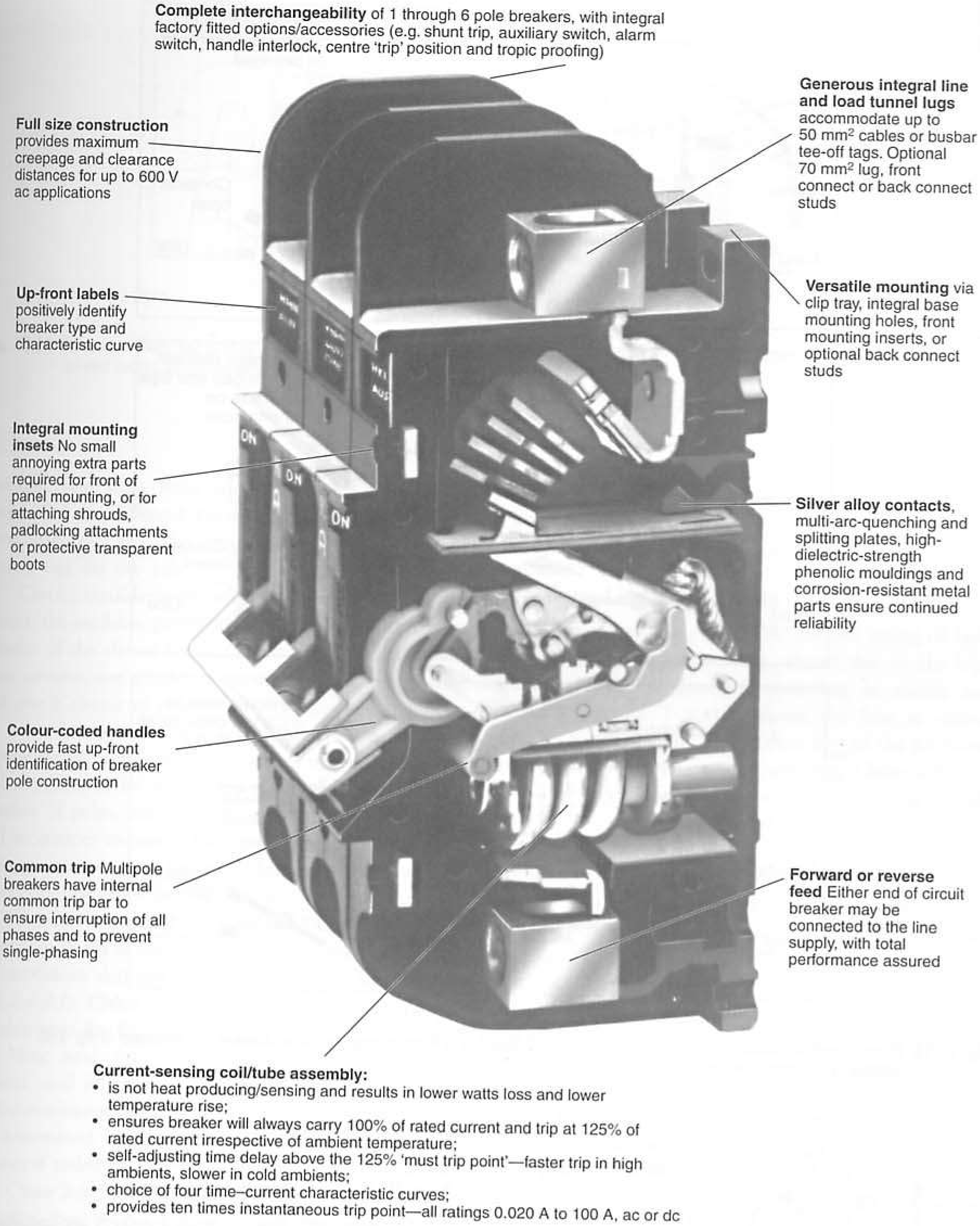


Fig. 13.15(b) *Hydraulic-magnetic circuit breaker: sectional view* HEINEMANN ELECTRIC

Operation of the grid depends on the fact that the arc established between the contacts is a current-carrying conductor surrounded by a magnetic field, the intensity of which is proportional to the magnitude of the current. The U-shaped metal plates distort the circular field around the arc, and the resultant field acts on the arc to push it into the plates, which cut the arc into a number of small sections. The cooling effect of the plates and the lengthening and cutting up of the arc cause it to be rapidly extinguished.

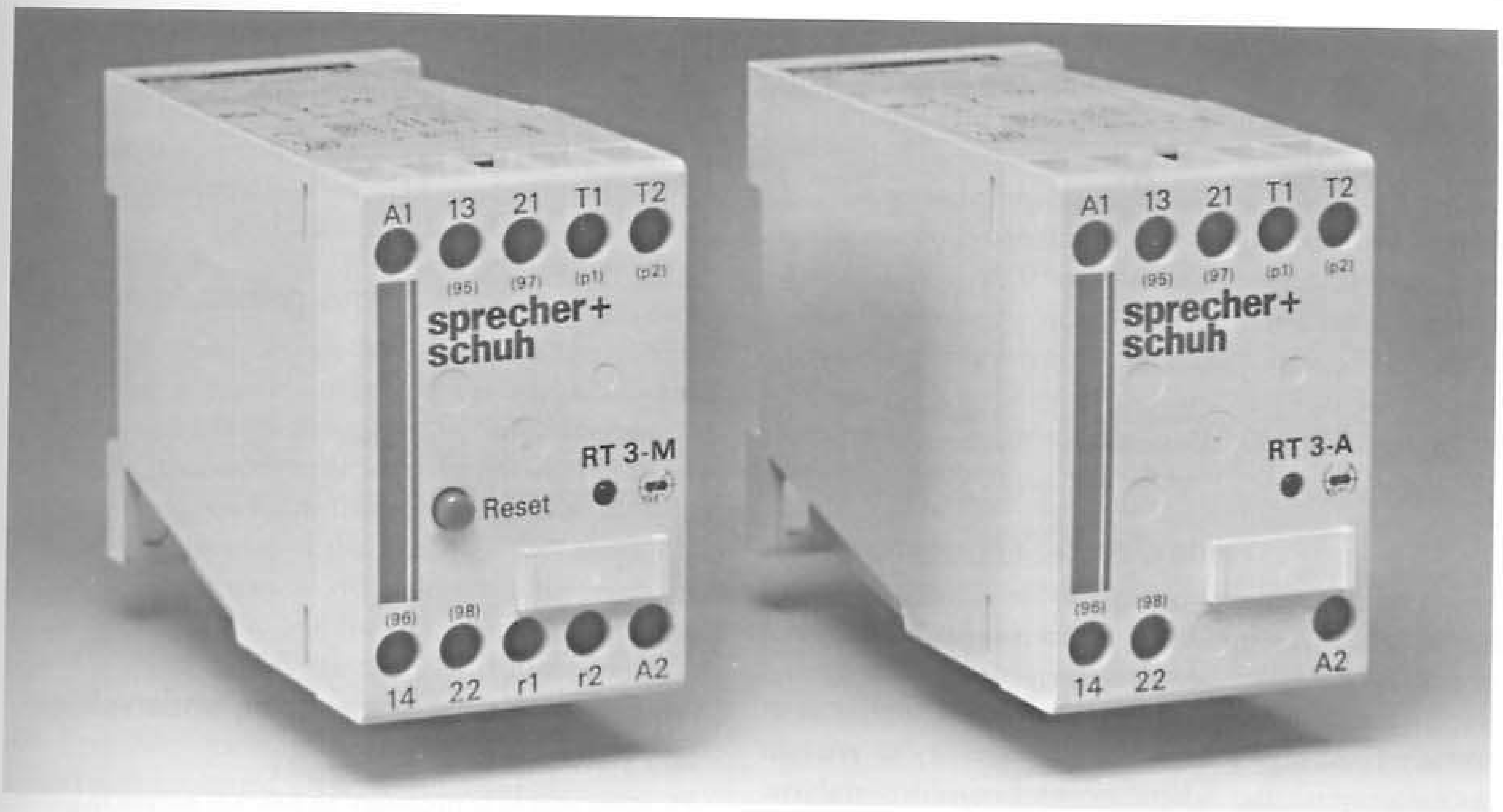


Fig. 13.28(b) *Thermal-element motor-protection switch. This unit is used in conjunction with PTC thermistors to protect motors from overload* NHP ELECTRICAL ENGINEERING PRODUCTS

Another electronic device that works on this principle, shown in Figure 13.31, calculates and displays motor shaft torque as a percentage of motor full-load torque. It also continuously calculates motor efficiency by measuring three-phase voltage and line current to the motor. Two independent relays are incorporated, enabling an output signal to be used if needed to stop the machine, sound an alarm or control other machinery. By the use of auxiliary inputs, the device can be programmed to display and react to line current, speed and temperature and may be linked to other electrical circuits or control signals. Locked rotor protection is also provided, a fault flag being displayed when motor current exceeds 500 per cent of full-load current for more than 3 seconds.

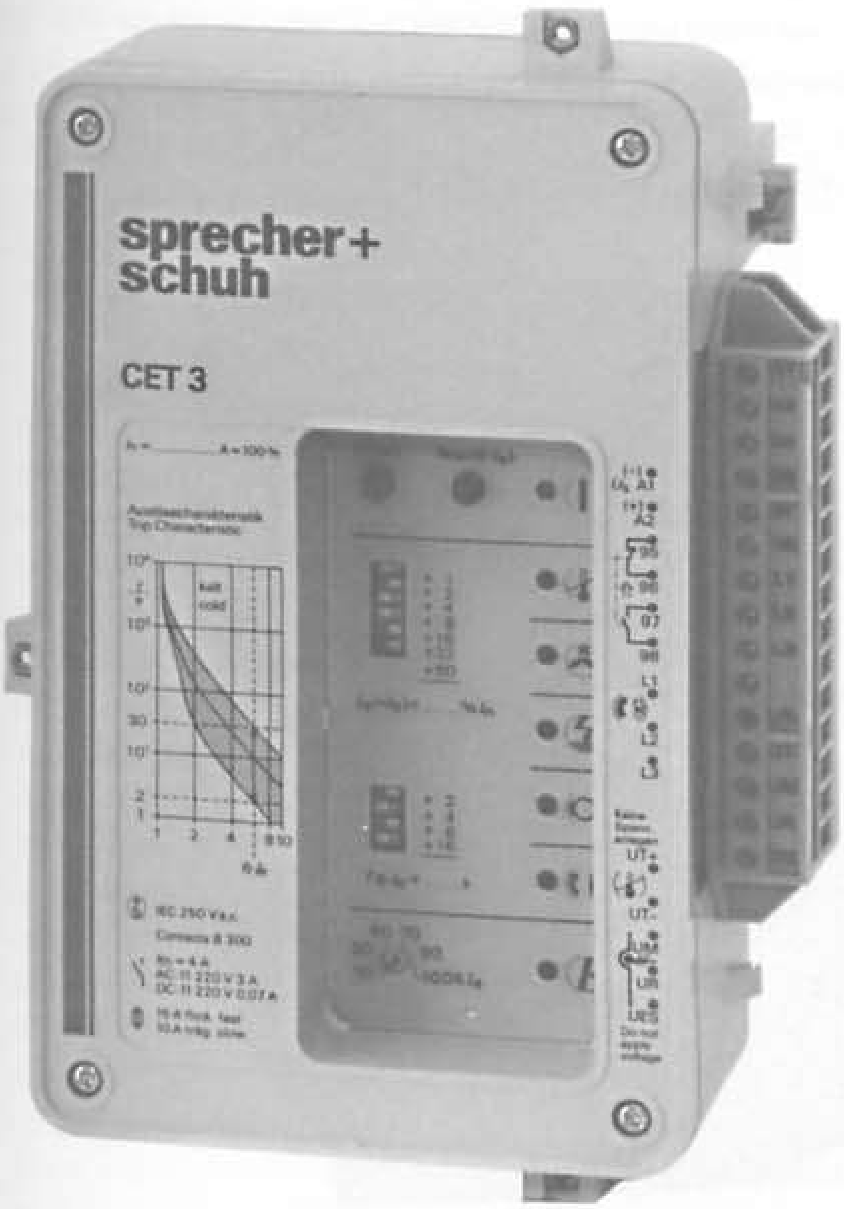


Fig. 13.29 *Electronic motor-protection relay* NHP ELECTRICAL ENGINEERING PRODUCTS

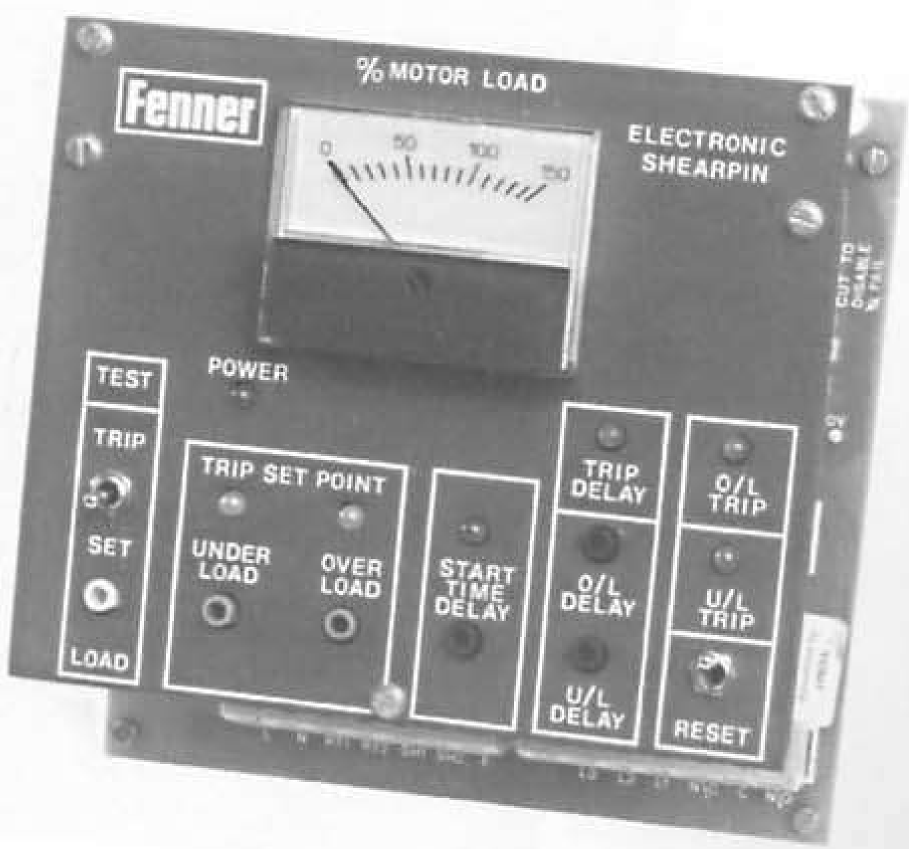


Fig. 13.30(a) *Electronic Shearpin control, which calculates motor-shaft torque demand* FENNER (AUSTRALIA)

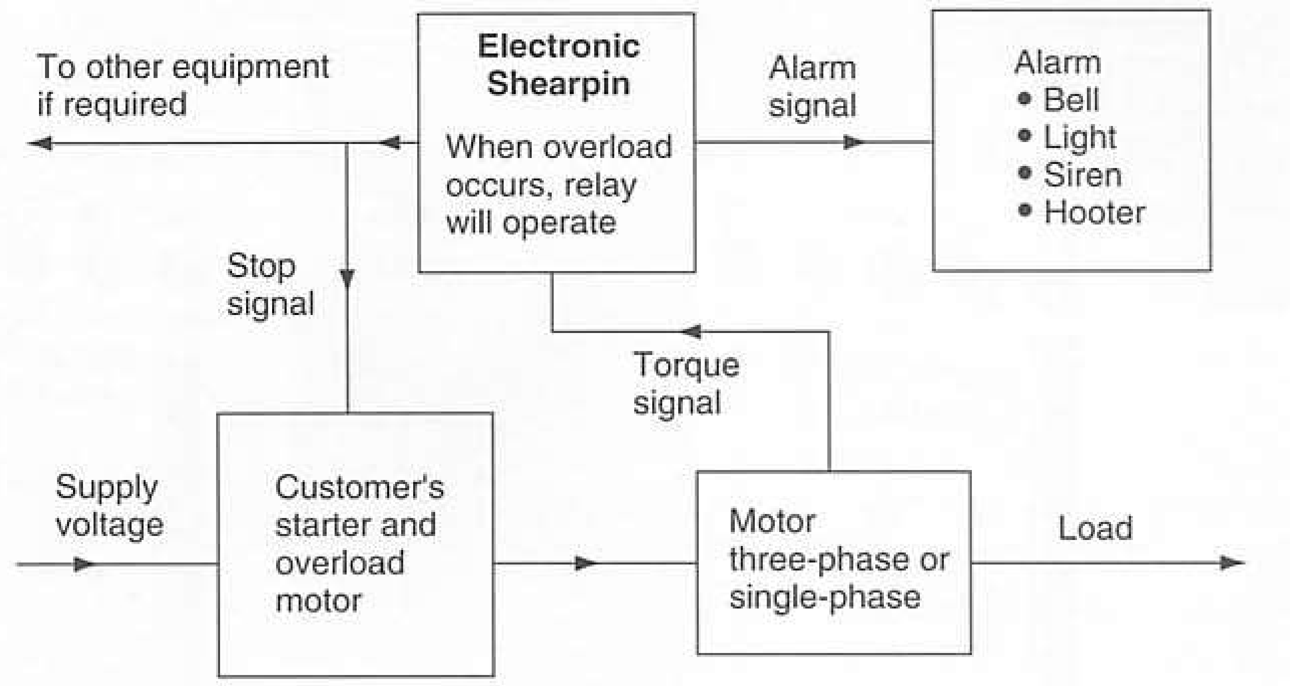


Fig. 13.30(b) *Typical application* FENNER (AUSTRALIA)

With any type of protective device, unless it is already fitted and calibrated, it is necessary to refer to manufacturers' data where cross-reference for ambient temperature, motor duty cycles, current ratings and other factors may be considered in choosing the correct protection in the calibration of the device. All the operating conditions should be known before a decision is made.

For overtemperature protection, AS 3000 specifies at least a single-pole trip (one supply line) for single-phase motors and also for two-wire dc motors with one supply line earthed. Double-pole tripping is specified for three-phase ac motors and dc motors supplied from two unearthed lines. It is usual to have three trips on three-phase circuits because interruption to an unprotected line could produce hazards such as single-phasing.

Protection against open circuit, undervoltage and automatic restarting

AS 3000 makes it necessary to provide means to prevent a motor restarting automatically after it has stopped due to low voltage or supply failure, if this could cause danger. The means to this end is usually provided by a 'no volt' or 'low volt' coil in the motor starter, which, when being energised, mechanically latches the starter in the 'on' position. If the starter is an automatic one, the 'run' hold-in coil performs this function. In either type, on low voltage (about 50 per cent of normal) or no voltage the coil will no longer retain its armature in the closed position, and the starter will revert to the 'off' position. Some positive action must then be taken by the operator to restart the motor, thus fulfilling the requirements of *Clause 4.15.5.*

Fig. 13.31 *Electronic control for drive and machinery protection* FENNER (AUSTRALIA)

The disadvantages of high installation costs and the high cost of maintaining the installation in good order, together with the problem of nuisance tripping, have resulted in the system's becoming virtually obsolete except for the special situations mentioned above.

Residual current devices (RCDs), described in Chapter 14, are commonly used to reduce the problem of voltage rise on an earthing system under fault conditions. They do not, however, constitute an earthing system but are used as a form of protection supplementary to the earthing system chosen.

12.5 Earth faults

You should study this section to gain a basic understanding of the effects on earth protection due to simple earth faults.

Causes of active-to-earth faults

Faults that affect the operation of the earthing system may occur:

- on the supply system to the installation;
- on an adjacent installation;
- in wiring or accessories;
- within appliances;
- in luminaires or switchboards.

The incidence of faults due to the first two causes is rare. Most faults are due to breakdown within installations of the last three groups of items.

Supply system faults

If a fault occurs on the supply system, this ideally operates the supply protection, leaving the consumer's installation unaffected, or at worst it should produce a temporary interruption to supply. Occasionally, however, faults do occur that can affect the consumer's earthing system, and in this regard the widely used MEN system is particularly vulnerable, due to the interconnection between the supply neutral and the consumer's earthing system.

Supply system faults are most often due to:

- reversed polarity of supply, or
- open circuit on supply neutral.

Reversed polarity of supply

Consider the effect of a supply connection error in which the active and neutral connections have been reversed at the point of attachment or at the street pole.

The direct-earthing system will be dealt with first. Recall that the only connection between neutral and earth is at the star point of the supply transformer, the circuit being similar to that of Figure 12.8 **without the neutral-to-earth connection** at each of the five consumers' installations. Due to the reversed connections, all single-pole switches will now operate in the neutral conductor, leaving a live active feed into an appliance with its control switch 'off'. Fuse or circuit-breaker protection is also in the neutral conductor, with the load actives all solidly joined at the previous neutral link (now an active link); consequently, there is no protection against overload due to an active-to-earth fault.

The earth-fault current resulting from the active-to-earth fault could cause a dangerous rise in potential in the earthing system and frames of appliances, resulting in shock and fire hazard.

If the system is ELCB protected (see Fig. 12.7), with reversed polarity there will be no protection of the wiring against overload, and a fire hazard will exist, as in the case of the direct-earthing system. However, if the earth-fault currents produce a voltage rise (20 V to 26 V) in the earthing system, the ELCB should trip, opening the neutral only, with no protection against the fault.

Now study the MEN system of Figure 12.5. Reversed supply polarity in this system will cause the active to be directly connected to earth (to short-circuit to earth) at the neutral link. High values of current will be present, and an immediate shock and fire hazard will be created, irrespective of the electrical condition of the installation. It is quite common for this fault to cause a switchboard fire and to burn off the main earth connection.

Open circuit on supply neutral

Remember that there will be no connection between neutral and earth at the consumer's installation if the installations are on either the direct-earthing or ELCB system. Therefore, if an open circuit or break occurs in the incoming supply neutral, say at point X_1 in Figure 12.8, supply will be interrupted, appliances and lights will fail to operate, and the fact that a fault condition exists will be clearly apparent.

Should the same fault occur when the installations are connected for the MEN earthing system, because of the connection between neutral and the main earth at the neutral link there will usually be no indication that a fault condition exists. All the installations on the load side of the break are using their earthing systems instead of the supply neutral as the return path for the normal load current.

The resistance of the earth-return path that has taken on the function of the return neutral is usually higher than the resistance of the neutral that it has replaced. The **load current** flowing in the earth-return path instead of the neutral usually produces a voltage rise due to *IR* drop, which is impressed on the whole of the earthing system, including the frames of appliances, whether they are switched on or not. This is a highly dangerous situation.

Earth bond or earthing bond: This is the connection between two metallic portions of an installation that must be maintained at the same earth potential: for example, a switchboard frame and electrical conduits, or an electrical metal conduit and a gas pipe in contact; and the connection between the earth electrode and the metallic water-supply system, if this exists (see Fig. 12.1).

Earthing continuity: This term refers to the necessity for making metallic cable sheaths or enclosures (such as trunking or conduits) both mechanically and electrically continuous, to provide a low-resistance path for any fault current to earth. It is sometimes referred to as the 'earth-continuity fault path' (see *Clause 3.26.4.5*).

Short circuit to earth: Sometimes termed a 'short to earth' or an 'earth fault', this is a fault that causes a potential to earth, resulting in a fault current to earth. The fault may be a short circuit of extremely low resistance, resulting in fault currents of high magnitude, or it may be a high resistance or 'partial short', which limits the value of leakage current.

Earth-fault current: As you may already have deduced, this is the current present in the earthing system caused by an earth fault.

Return earth circuit: Sometimes termed an 'earth loop' or simply an 'earth fault circuit', this describes the complete lead and return path traversed by the earth-fault current (see Fig. 12.2).

Stray earth currents: Often present in the soil, these are currents in the earth section of the earth loop that are due to causes such as leakage current from distribution systems or electric traction systems.

Stray earth currents are sometimes a safety

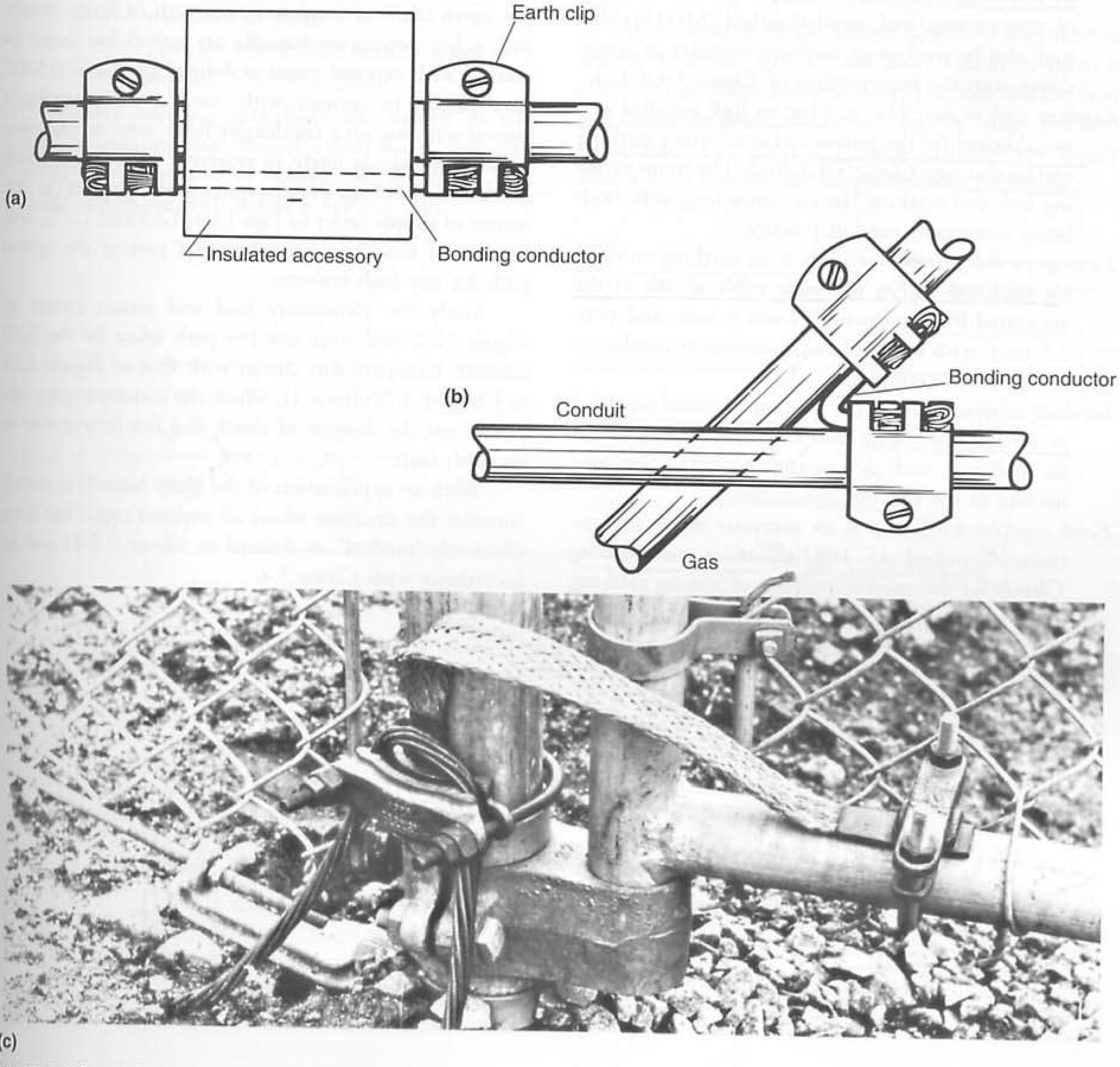


Fig. 12.1 **(a)** *and* **(b)** *Bonding connections* **(c)** *Earth bonding to prevent voltage rise in a substation gate* BURNDY INC

12.4 Earthing systems

When the term 'earthing' is used, it means a system of connection to the general mass of earth. This requires connection to earth at the supply source as well as at the consumer's installation. Most public systems are 'earthed'; the few isolated exceptions do not come within the scope of this chapter. It is intended here to deal only with the 415/240 V 'star system' of distribution in regard to earthing requirements and the *SAA Wiring Rules*. During your career you will encounter many other sources of supply, which are earthed mainly for safety reasons.

The necessary measures to be taken by energy distributors with regard to earthing are dealt with in a *Code of Earthing Practice*, which is complementary to the *SAA Wiring Rules* used for consumers' installations. The purpose of this code is to provide guidance to energy distributors in ensuring that effective earthing facilities are available to the consumer, and to assist in 'achieving a satisfactory and uniform standard of protective earthing'.

The code describes the use and application of three recognised systems of earthing specified in the *SAA Wiring Rules*:

- the direct-earthing system;
- the multiple-earthed neutral (MEN) system;
- the earth-leakage circuit breaker (ELCB) system.

Figures 12.4, 12.5 and 12.7 show the basics of distributors' and consumers' earthing arrangements for each of these systems.

Clause 5.2.1 of the *SAA Wiring Rules* requires the energy distributor to specify which system is to be used within its own supply area or portion of the area, and it is the distributor's responsibility to ensure that the electrical installations comply with the conditions and Rules that apply to the particular system. Although desirable, the earthing system generally adopted within an area may not be applied in every section of that area; for example, the distributor may require a certain section to be ELCB protected, if deemed necessary for safe operation.

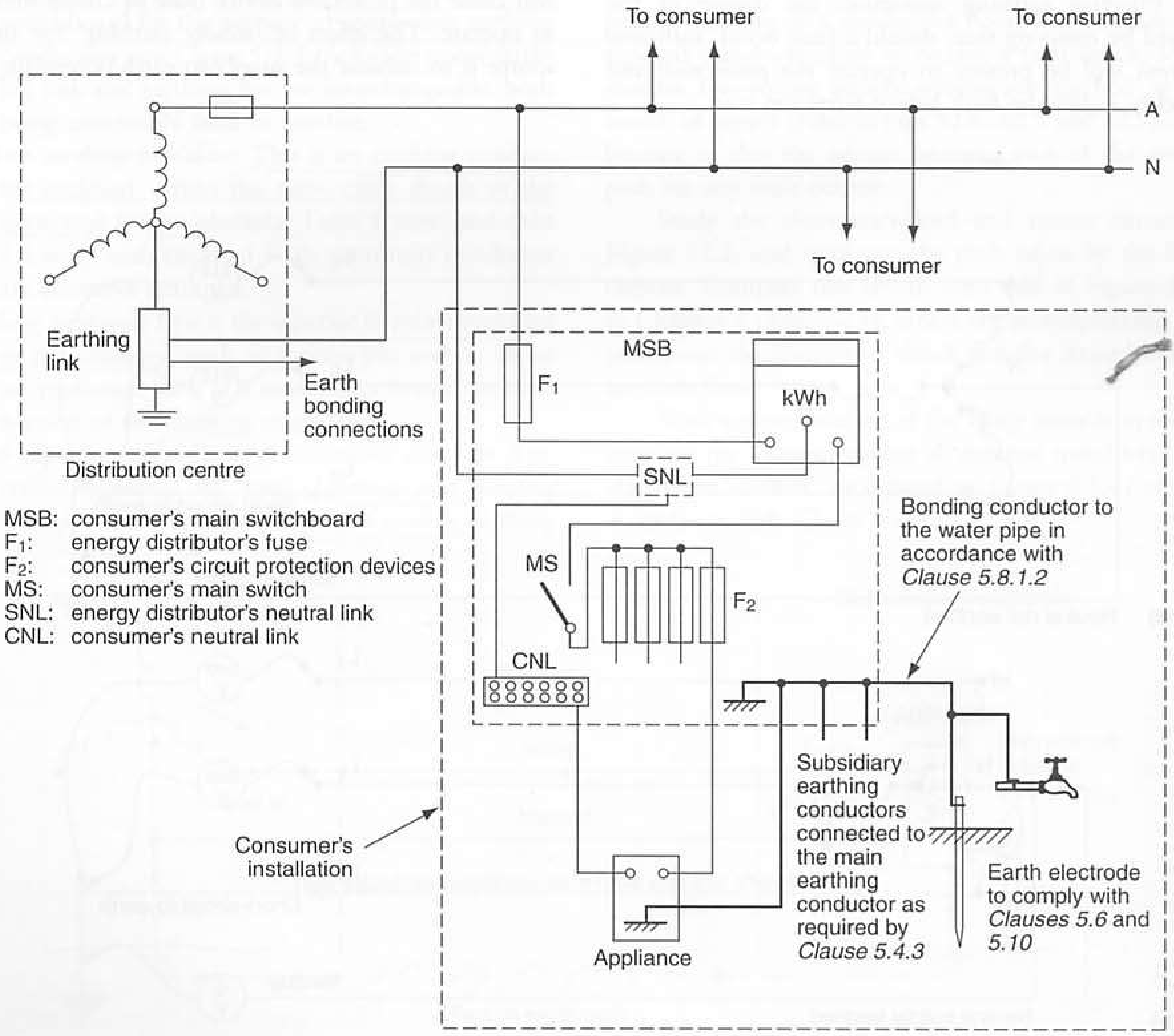


Fig. 12.4 *Direct-earthing system*

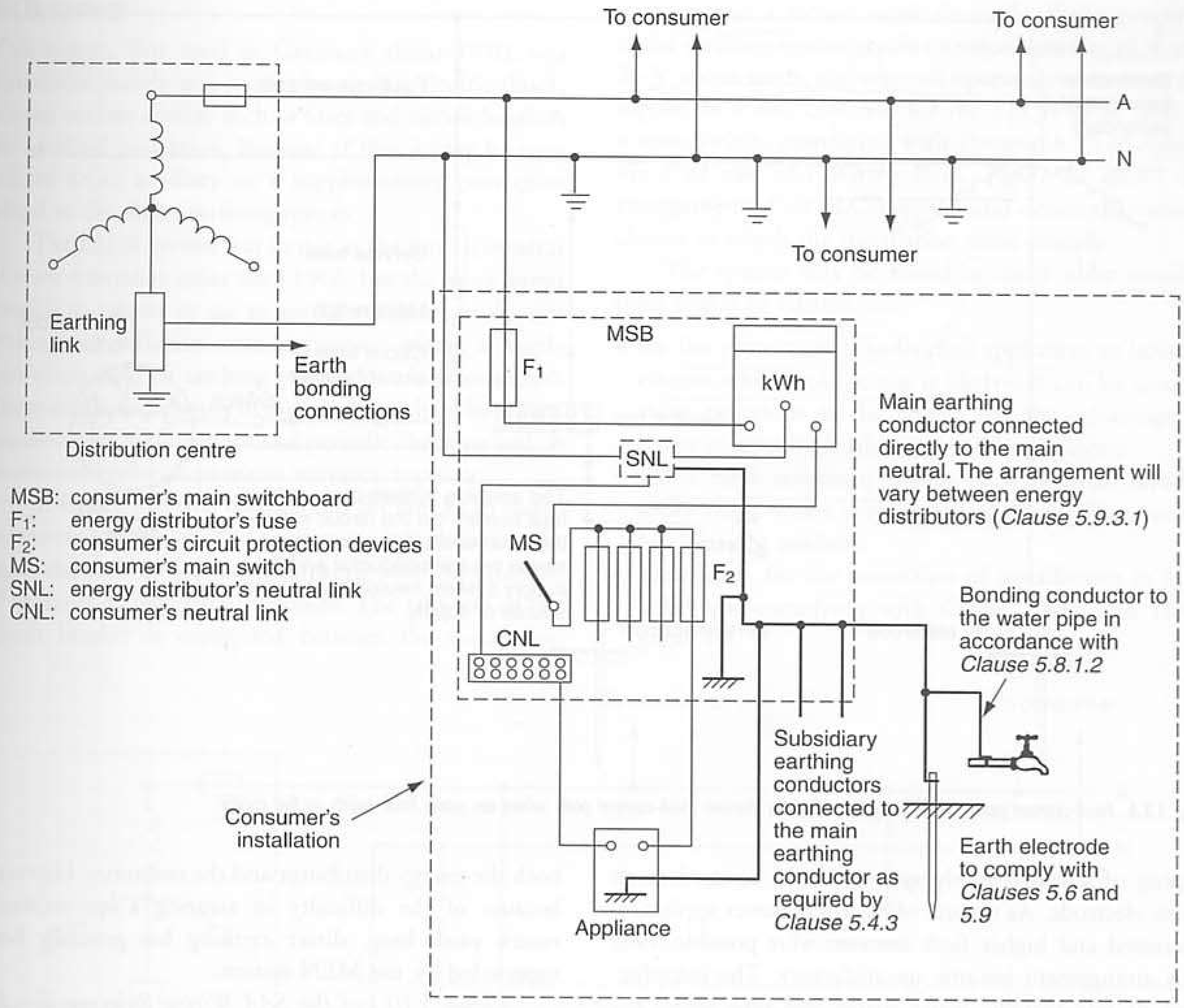


Fig. 12.5 *Multiple-earthed neutral (MEN) system*

Operating principles

The direct-earthing and MEN systems are current-operated systems. These systems operate to isolate the faulty section of an installation when the value of fault current is sufficient to rupture the fuse or trip the circuit breaker.

If the earth-loop-return resistance is too high, the fault current may be too low to operate the circuit protection device. Applying Ohm's Law, $V = IR$, it can be seen that high resistance coupled with low current will result in a dangerous rise in potential between a fault, say the frame of an appliance, and the general mass of earth, say a concrete floor. For example, a current of 1 A, not high enough to rupture a fuse, would produce a voltage drop of 200 V across a return path of 200 Ω. When these systems are used, measures are taken to ensure that the earth-loop-return resistance is as low as possible. Fault current paths in a MEN system are shown in Figure 12.6.

The ELCB system is a voltage-operated system. This system operates to isolate the faulty section of an installation when the potential on the installation earthing rises above a set value. The rise in potential is detected by the trip coil of the earth-leakage circuit breaker. This system is independent of the resistance of the earth loop return. However, the system cannot discriminate between earth fault currents and other conditions that could cause a rise in the potential of the installation earthing. These other conditions could be currents through the earth due to faults in adjacent installations or electrical storms. This may cause 'nuisance tripping'.

Direct-earthing system

The original system in common use was the direct earthing of equipment required to be earthed by connection to an earth stake or earth electrode driven into the ground.

Under these conditions, the resistance of the return path was often high, thus leading to the position that direct earthing was used only where a relatively low-resistance metallic return path, such as the metallic

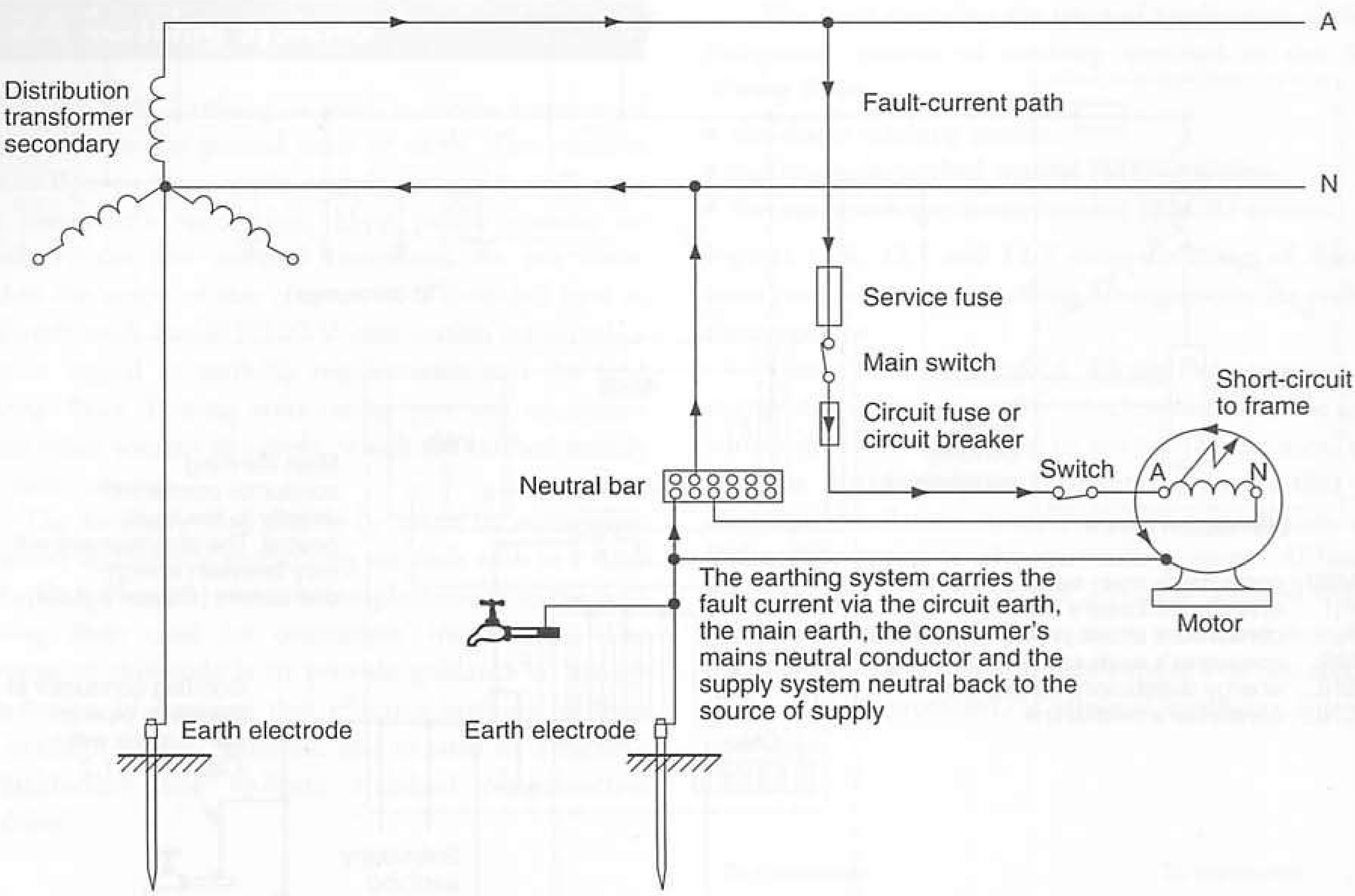


Fig. 12.6 *Fault-current paths in MEN system. Arrows denote fault-current path when an earth fault exists in the motor*

piping of a water-supply system, could be used as an earth electrode. As the use of electrical power appliances increased and higher fault currents were possible, even this arrangement became unsatisfactory. The introduction of non-metallic water mains and pipe joints has further aggravated the provision of a satisfactory earth-loop-return path for direct earthing.

As a result, in the direct-earthing system the *Code of Earthing Practice*, used by energy distributors, requires them to provide a bonding connection to:

1. the metallic water-pipe system,
2. an underground system of metallic cable sheaths, or
3. a special earthing conductor that is linked to the supply neutral, transformer star point and low-voltage earthing grid or mat at the distribution transformer.

Method 1 is common but is still limited to areas where a metallic piping is used for the reticulation of water. Method 2 is restricted to areas where supply is by metal-sheathed underground cables. Method 3 is the least used and is usually installed only when the supply source and the consumer's installation are adjacent. An example would be a large factory supplied from its own substation feeding directly into the main switchboard for the installation.

In Figure 12.4 the connections for a direct-earthing system are shown. Note that there is no connection between the neutral and earth within the consumer's installation. It is the simplest system, from the view of both the energy distributor and the consumer. However, because of the difficulty in assuring a low-resistance return earth loop, direct earthing has generally been superseded by the MEN system.

Clause 5.10.1 of the *SAA Wiring Rules* specifies the maximum electrode-to-earth resistance; however, this can be difficult to maintain in practice. *Clause 5.10.2* allows the energy distributor to nominate alternative main earth connections for this system.

MEN system

The MEN system is the most widely adopted system, as supply engineers consider that its practical advantages outweigh its disadvantages. In this system the metallic return is provided mainly by the supply neutral conductor, which is in parallel with any other return path, such as the general mass of earth (earthing system network) and the bonded metallic water pipes.

In Figure 12.5 the connections for a MEN earthing system are shown. The only difference at the consumer's installation between this system and direct earthing is the connection of the installation earth to the main neutral. Because there is a connection between the neutral and the earthing system at each consumer's installation, as well as on the low-voltage distribution, the resistance of the earth-loop-return path is kept low. This multiple earthing of the neutral has given the system its name of multiple-earthed neutral system.

ELCB system

This system, first used in Germany about 1910, was introduced mainly as a protection against electric shock, leaving current devices such as fuses and circuit breakers for overload protection. Because of this it may be considered as an auxiliary or a supplementary protection added to the direct-earthing system.

The ELCB system was in use in the inner-city areas of some Australian cities until 1966, but the more recent trend is to restrict its use to special machines or circuits within an installation or to a situation within a supply area where difficult earthing conditions are encountered. The system is more costly to the consumer than the others, requires more maintenance and periodic checking and, as mentioned earlier, is prone to nuisance tripping.

In Figure 12.7 the connections for an ELCB earthing system are shown. The consumer's installation earthing is the same as for direct earthing, with the addition of an earth-leakage circuit breaker. The trip coil of the circuit breaker is connected between the installation earthing and a second earth electrode. If the potential of the earthing system reaches a value between 20 V and 26 V above earth, the trip coil operates and isolates the supply. It is also common for the ELCB to be used as a main switch, complying with *Paragraph F5* of *Appendix F* of the *SAA Wiring Rules. Figure F1* shows the arrangement of an ELCB system and details the various clauses to which the installation must comply.

The system may be found in many older installations and is in current use:

- for the protection of individual appliances or isolated circuits where voltage rise is likely—it can be used in these situations as the system has the advantage of being compatible with other earthing systems
- where earth resistance is high, such as on an isolated rocky ridge, where direct earthing is not effective and MEN is not available
- sometimes, for the protection of installations in outbuildings, complying with *Clause 5.10.3* and *Paragraph F3*.

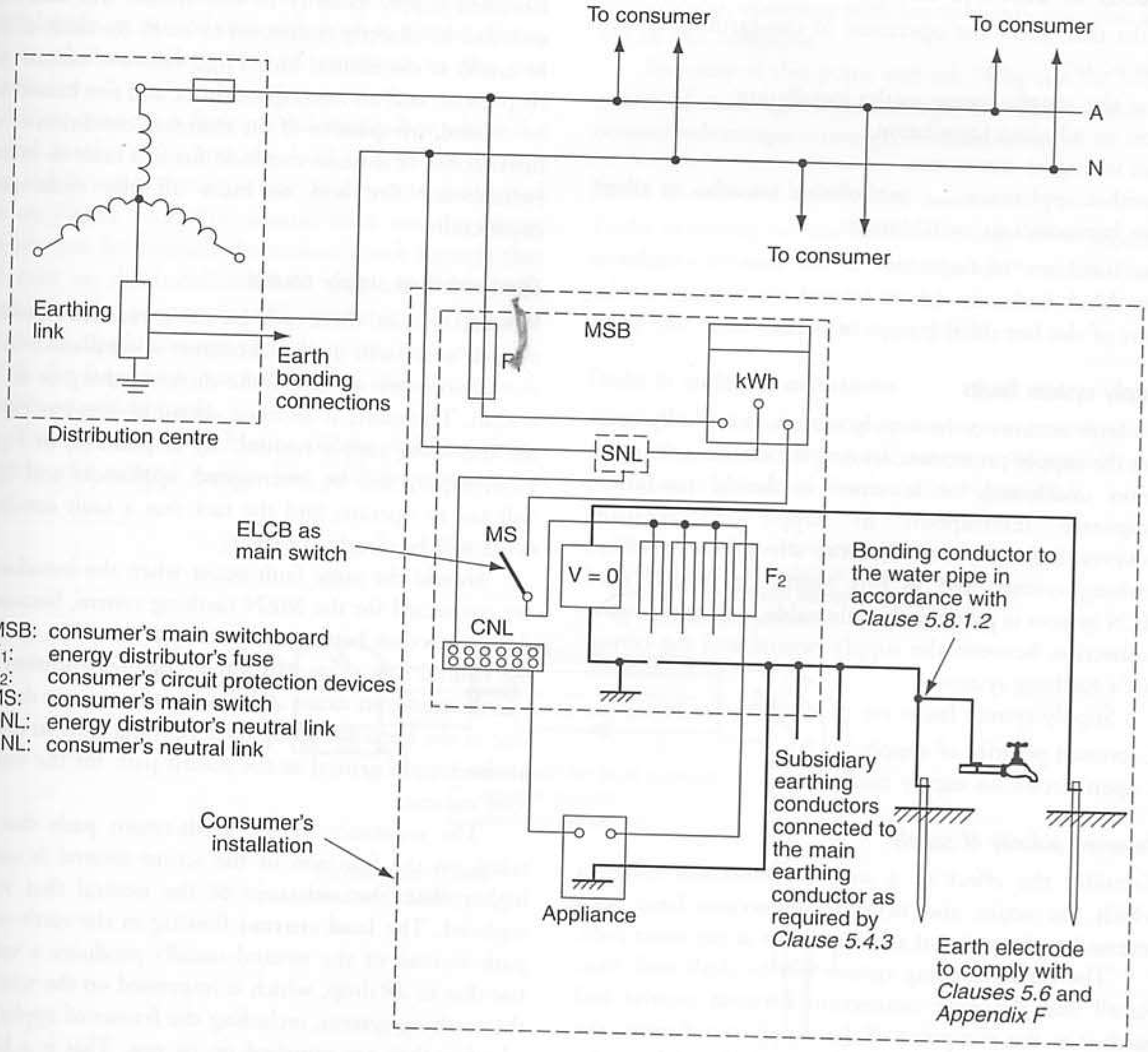
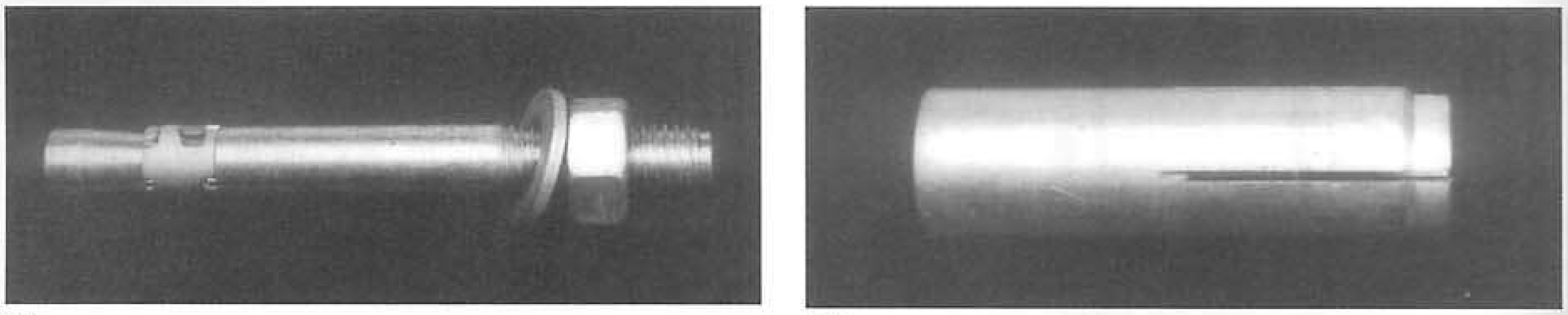


Fig. 12.7 *Voltage-operated earth-leakage circuit breaker (ELCB) system*



(a) (b)

Fig. 5.4 *Anchors for use in concrete or natural stone:* **(a)** *universal stud anchor; (b) internally threaded anchor, for which a setting punch is required* HILTI (AUSTRALIA)

The principle of using an insert that expands when load is applied and thus jams firmly in a neat hole has been widely applied in many other forms, by various manufacturers, for fixing accessories. This principle is illustrated in Figure 5.4.

Bolts or other fixing anchors may be cemented in position during a concrete 'pour', or fixed after the concrete is set into a hole by grouting in with cement. Molten lead and molten sulphur have both been used in lieu of cement grout, or sometimes lead wool, which is tamped down in the hole space to secure the masonry anchor. However, these practices have been largely superseded by more refined methods of fixing.

One method uses an 'adhesive anchor', which is a two-part system comprising an adhesive cartridge and anchor rod with nut and washer. After the hole is drilled and cleared of dust and loose material, a two-section glass cartridge containing an epoxy-acrylate resin in one section and a hardener in the other is inserted into the hole. Driving the anchor rod into the cartridge breaks the glass, mixing the two chemical components together. Curing time is 20 to 30 minutes under average conditions, and the adhesive is unaffected by moisture even if present at the time of fixing.

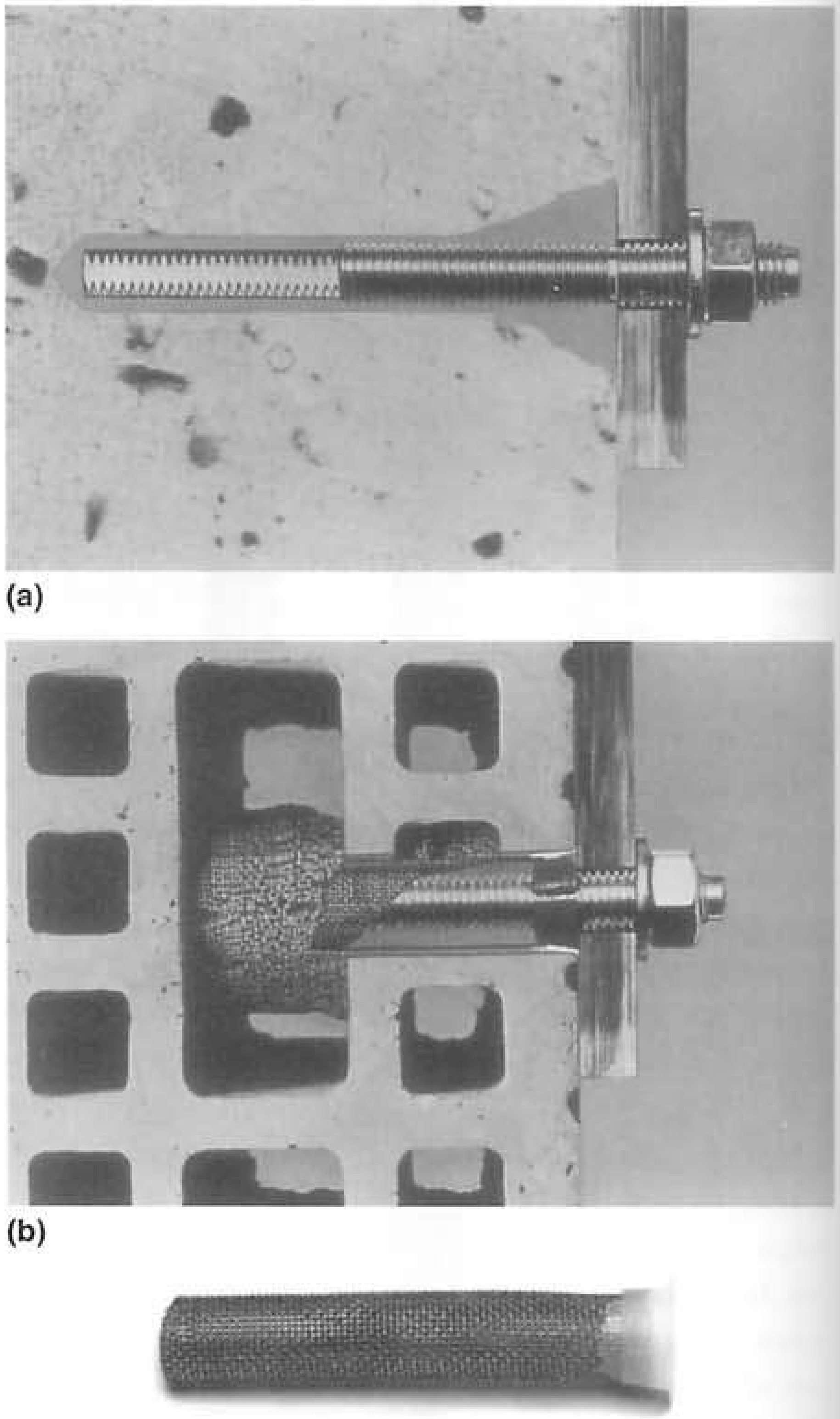
Another anchoring method uses a two-part adhesive injected from a cartridge containing unsaturated polyester, mounted in a dispensing tool. It is particularly suitable for fixing a stud in hollow masonry or blockwork. Cartridges containing a modified epoxy-acrylate are also available for using this method for fixing in solid masonry, concrete or rock.

A 'sieve sleeve' may be used in hollow masonry (as shown in Fig. 5.5(b)) to prevent setting compound from dropping away into cavities. It also allows the material to squeeze out, forming an anchor when set, and acts as reinforcement for the adhesive.

For fixing most anchors it is important to select the drill bit diameter to suit the anchor diameter and to ensure that the hole depth is correct. In the case of adhesive-type anchors and injection systems, it is also necessary to clean out the drilled hole before setting the anchor.

Fixing to wall boards and metal

Accessories have been developed for fixing to wall sheets of relatively thin material such as plaster, fibrous cement or hardboard, and typical examples are shown in Figure 5.6. The principles involved are apparent from a study



(a)

(b)

(c)

Fig. 5.5 *Injection system anchoring for difficult base material:* **(a)** *fixing in solid material;* **(b)** *anchoring in hollow masonry;* **(c)** *sieve* HILTI (AUSTRALIA)

Fig. 5.9 *A deep-type round PVC junction box* GERARD INDUSTRIES

Figure 5.11(b) shows a steel mounting bracket, primarily intended for use in timber-framed construction, which is usually fixed to the studs and sometimes called a 'stud bracket'. It is manufactured in the form shown, where fixing is to the side of the stud, or as a flat plate, for fixing to the front of the stud. There are several sizes to suit different accessories.

Fig. 5.10(a) *Wall box* HPM INDUSTRIES

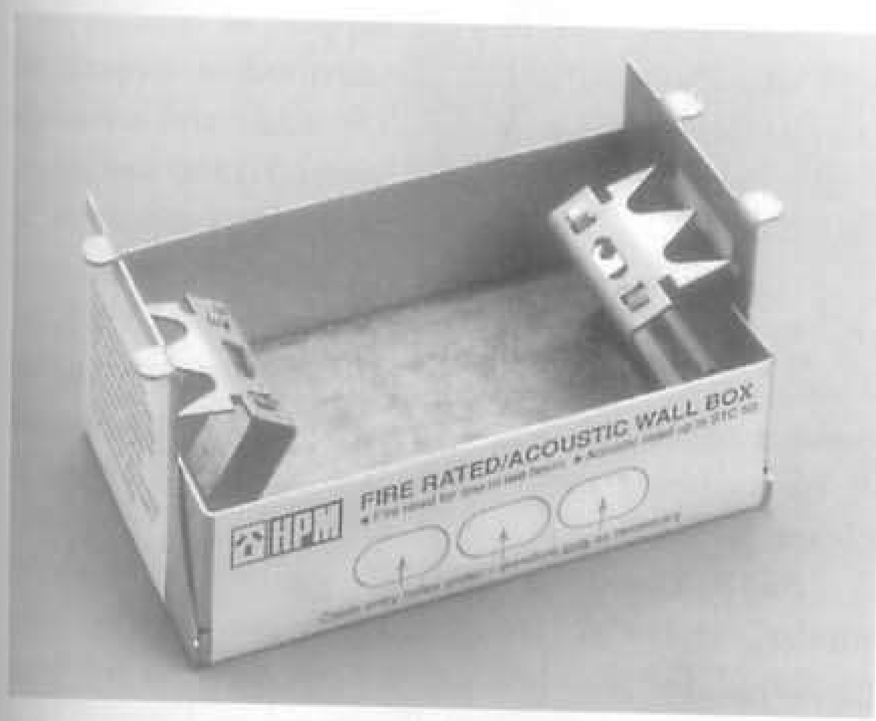


Fig. 5.10(b) *Fire-rated and acoustic wall box* HPM INDUSTRIES

Fig. 5.10(c) *PVC wall box* HPM INDUSTRIES

For additions to an existing wiring installation, a most convenient mounting bracket type is shown in Figure 5.12. It is designed for fixing to thin walls such as those composed of fibrous cement, plaster or hardboard sheets, where it minimises wall damage and saves labour. It is made in several sizes to fit different accessories and different wall thicknesses.

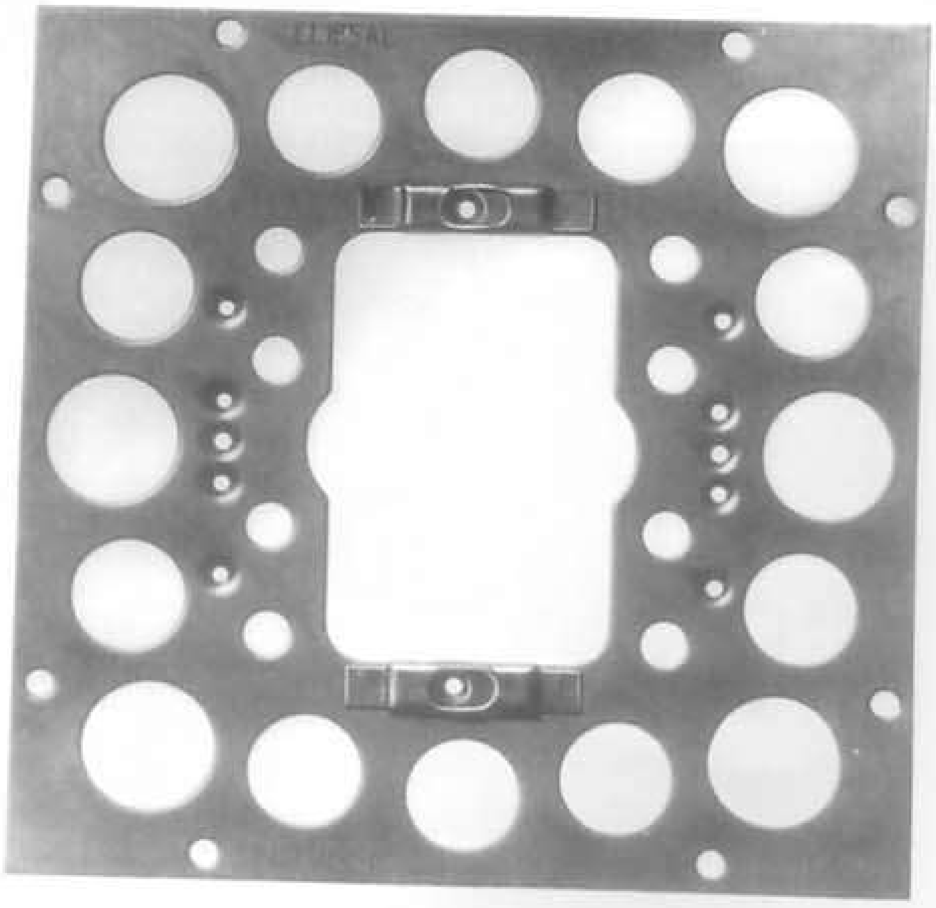


Fig. 5.11(a) *Plaster-mounting metal bracket* GERARD INDUSTRIES

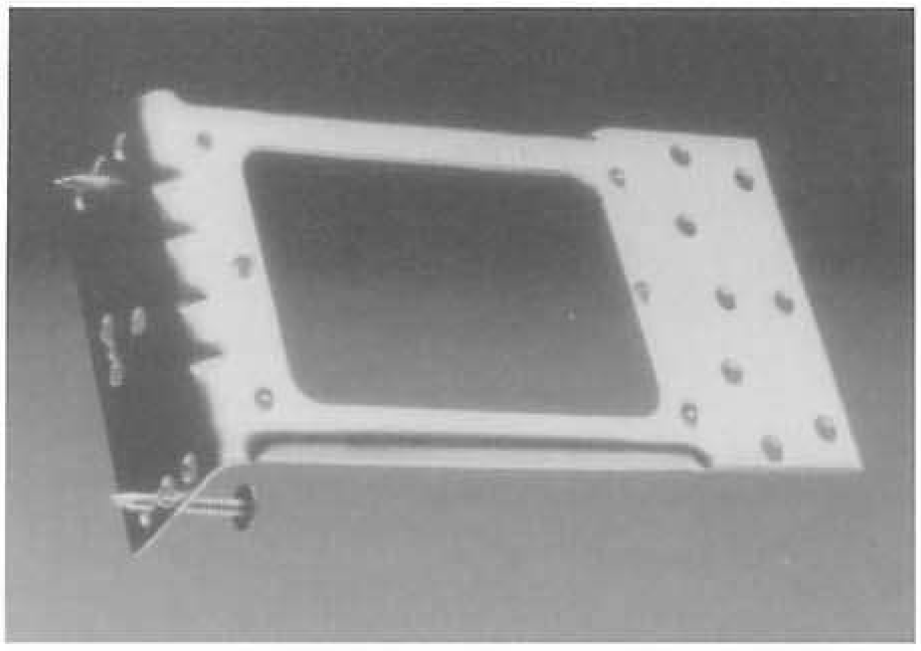


Fig. 5.11(b) *One-gang standard-pattern horizontal metal mounting bracket, also available in a vertical mounting pattern*
GERARD INDUSTRIES

Fig. 5.12 *Plaster or wallboard metal mounting bracket*
HPM INDUSTRIES

Accessories for surface mounting

For the surface mounting of accessories with exposed wiring, or where necessary with concealed wiring, plastic surface-mounting blocks such as that illustrated in Figure 5.13 may be used. Direct mounting of an accessory on a surface-type junction box is also possible. The mounting of accessories on wooden blocks as seen in old installations is generally redundant but is sometimes used in the restoration of older buildings and houses.

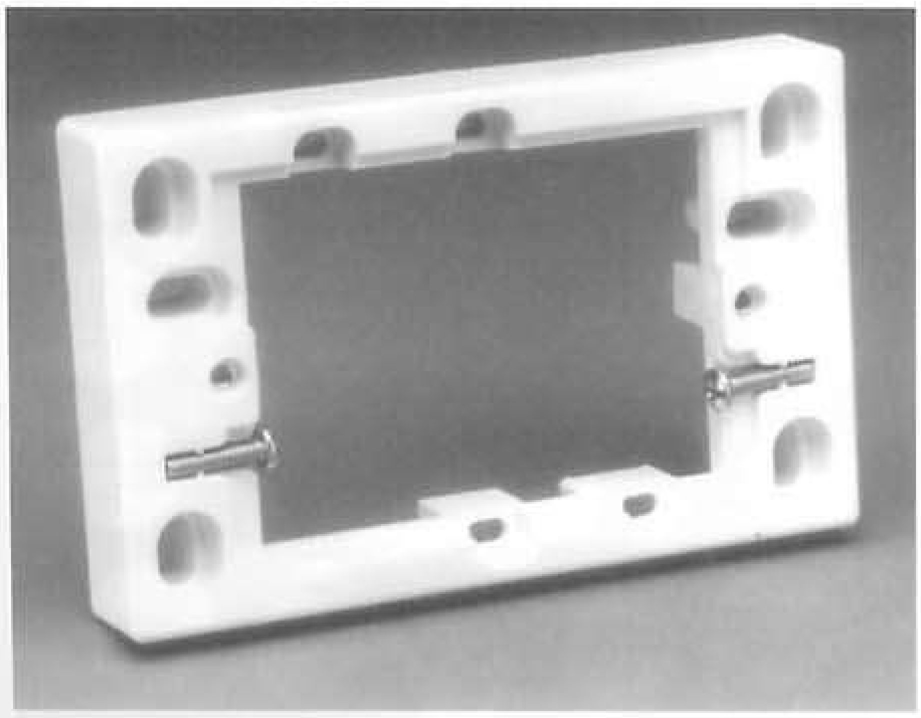


Fig. 5.13 *Single-gang plastic mounting block, available in depths of 13 mm, 18 mm and 37 mm* HPM INDUSTRIES

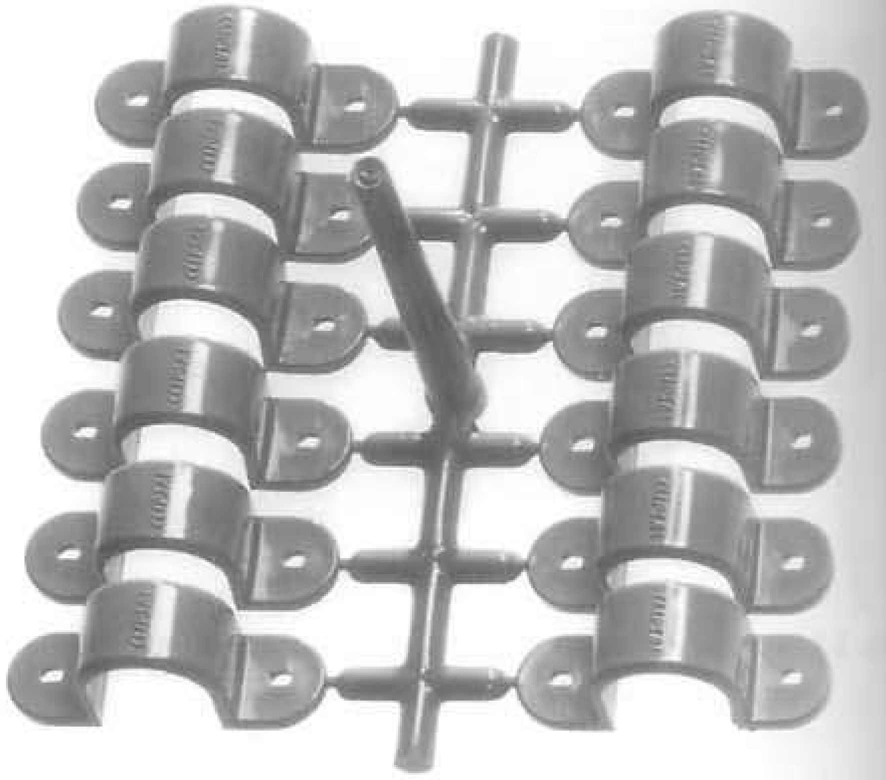


Fig. 5.14(a) *PVC saddles as they emerge from the mould*
GERARD INDUSTRIES

Fig. 5.14(b) *Steel conduit saddle and half-saddle* GERARD INDUSTRIES

Fig. 5.14(c) *A PVC saddle spacer* GERARD INDUSTRIES

Accessories used for the support of conduit, both steel and PVC, vary with the method of support, the most common being the conduit saddle and half-saddle or clip, which are shown in Figures 5.14(a) and (b).

Where specifications require the conduit to be spaced away from the supporting wall or structure, some type of saddle spacer is used (see Figs 5.14(c) and 5.16). There are several forms of saddle clip for attaching the conduit to structural steel beams, some being patented or of registered design, such as the one illustrated in Figure 5.15.

Support systems for PVC or steel conduits are similar, and the same support systems are often employed for sheathed cables, especially in the larger sizes. The support system illustrated in Figure 5.16 is suitable for mounting conduits that are to be run

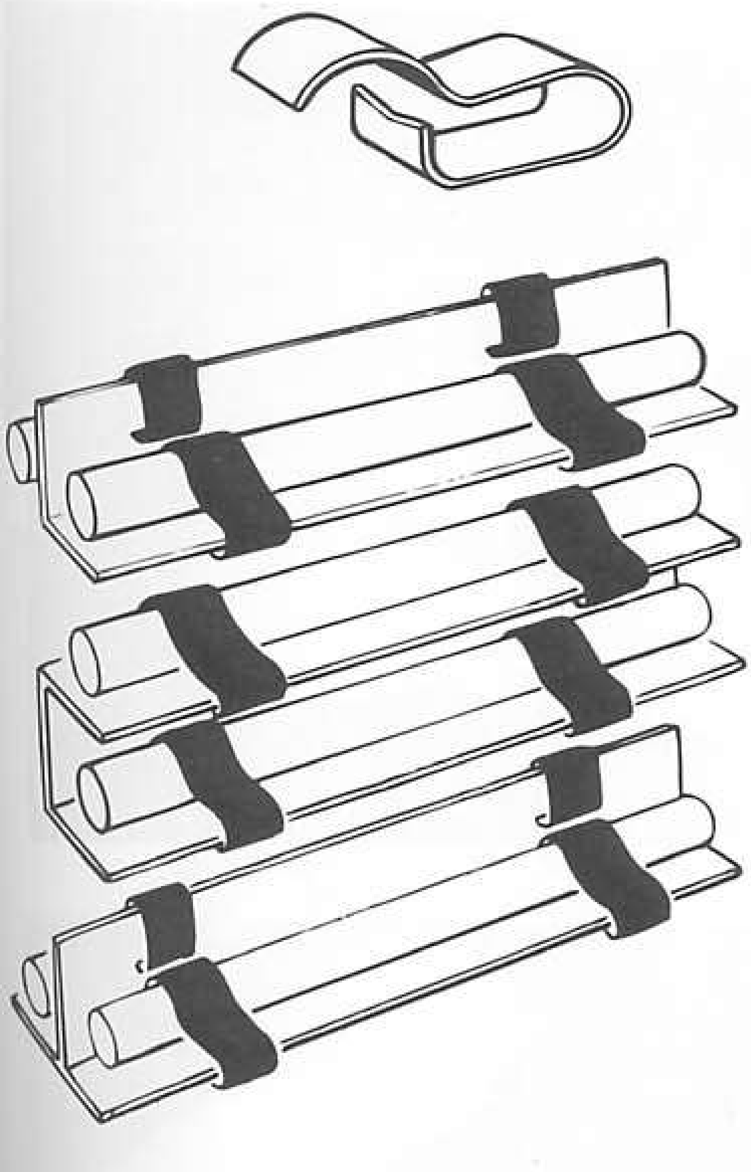


Fig. 5.15 *Spring-clip conduit saddles* SLEGERS PRODUCTS

adjacent to each other. The plastic mounting channel, which is provided with an interlocking tongue for additional runs of conduit, accepts plastic mounting clips available in sizes from 16 mm to 50 mm.

Support for TPS wiring is largely provided by the building structure itself in positions 'where not likely to be disturbed' (refer to Chapter 8, section 8.4). Continuous support in other situations is provided by the surface on which the TPS wiring is installed, by cable trunks or troughs, cable trays or similar means.

For fixing TPS cables to a surface, the metal pin clips or plastic mounting clips illustrated in Figure 8.4, Chapter 8, are most commonly used. Cable ties are also commonly used for fixing TPS cables to flat surfaces and cable trays, using various types of mounts, some of which are shown in Figure 5.17(a)–(d).

There are various other special support accessories that have been designed for special wiring methods; as an example, one large manufacturer of electrical products supplies accessories for a loom wiring system designed primarily for rows of lighting units, which are plugged into a prefabricated wiring system erected on the underside of, or in a suspended ceiling below, floor slabs in concrete buildings (see Fig. 5.18).

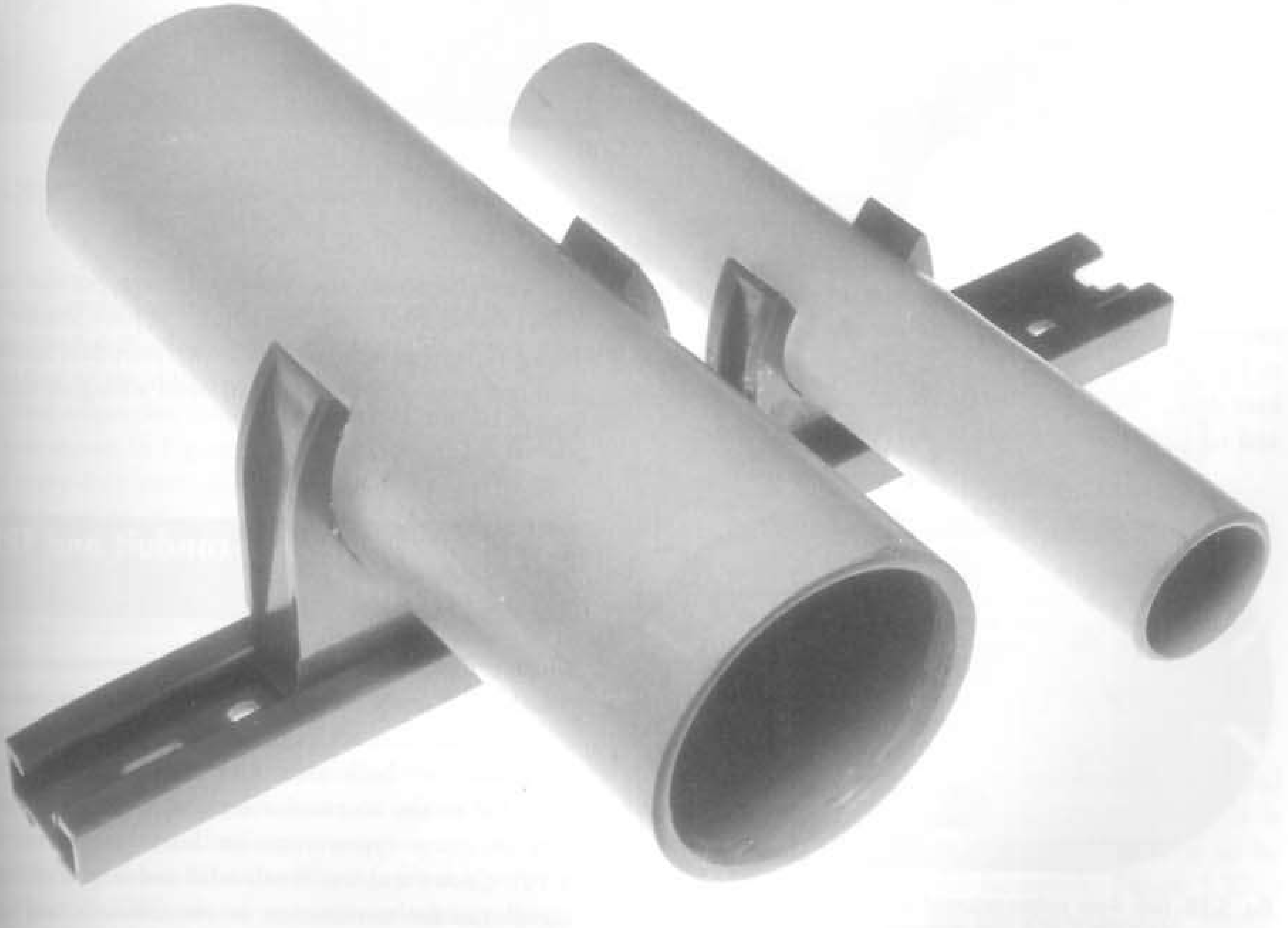


Fig. 5.16 *Fastening system for multiple runs of conduit* GERARD INDUSTRIES

Fig. 5.19 *Typical solid PVC 90° bends* GERARD INDUSTRIES

Fig. 5.20 *PVC inspection-type elbow and tee* GERARD INDUSTRIES

system. Comprehensive listings of all types will be found in manufacturers' catalogues, but a few illustrations representative of the different groups follow.

Steel inspection elbows and tees of similar design to those shown in Figure 5.20 are also available for use with heavy-duty steel conduit.

Figure 5.21 illustrates some typical PVC conduit couplings readily available on the Australian and New Zealand market. It should be noted that the screwed couplings illustrated are intended for use with other moulded accessories. PVC conduit should never be threaded, but a 'screwed-to-plain conduit reducer' may be used.

Protection of conduit ends, and prevention of the entry of dirt, cement, plaster, water or other matter, are important where building operations are in progress. Figure 5.22(a) shows conduit end plugs for this purpose.

Figure 5.22(b) shows a conduit-locating flange, which serves the dual purpose of conduit location and

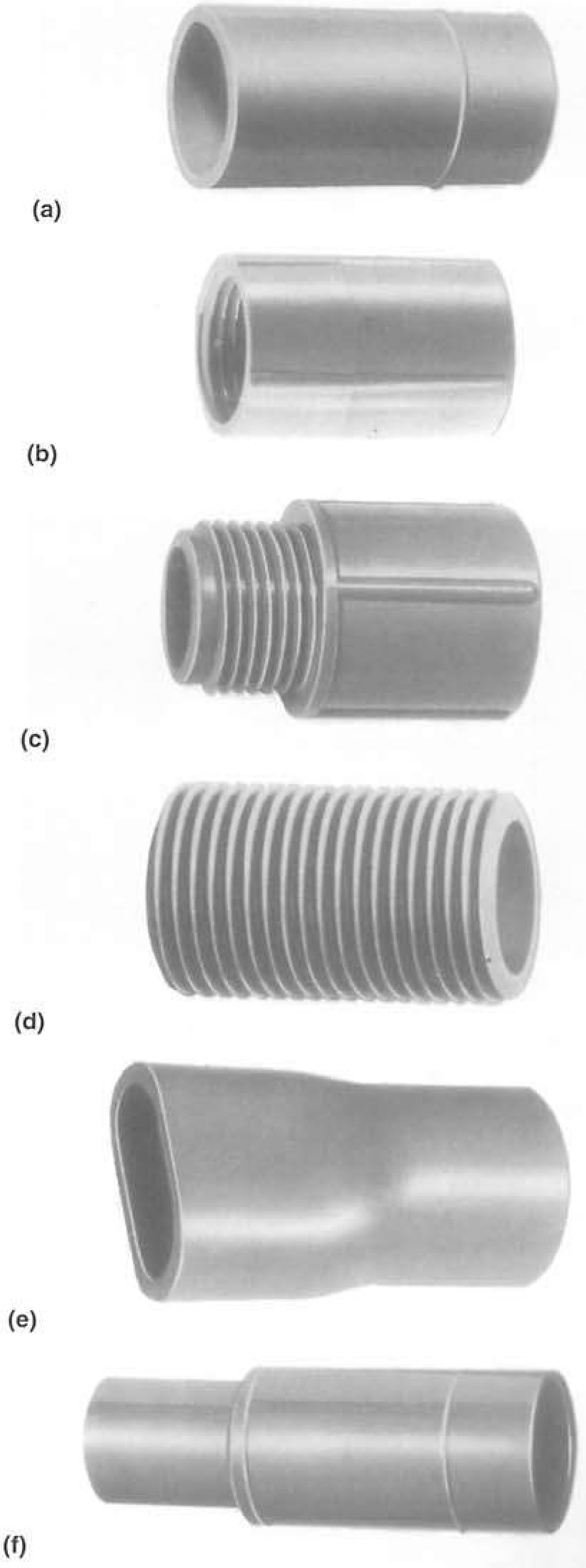


Fig. 5.21 *Typical conduit couplings:* **(a)** *plain coupling;* **(b)** *screwed coupling;* **(c)** *screwed-to-plain conduit adaptor;* **(d)** *screwed nipple;* **(e)** *round-to-flat conduit adaptor;* **(f)** *expansion coupling* GERARD INDUSTRIES

protection on concrete jobs where conduit is turned down for penetration of a floor slab, or where it is carried through a poured concrete wall and is to be extended on removal of the formwork. Figure 5.22(c) shows a disposable lid for the protection of round-junction-box outlets.

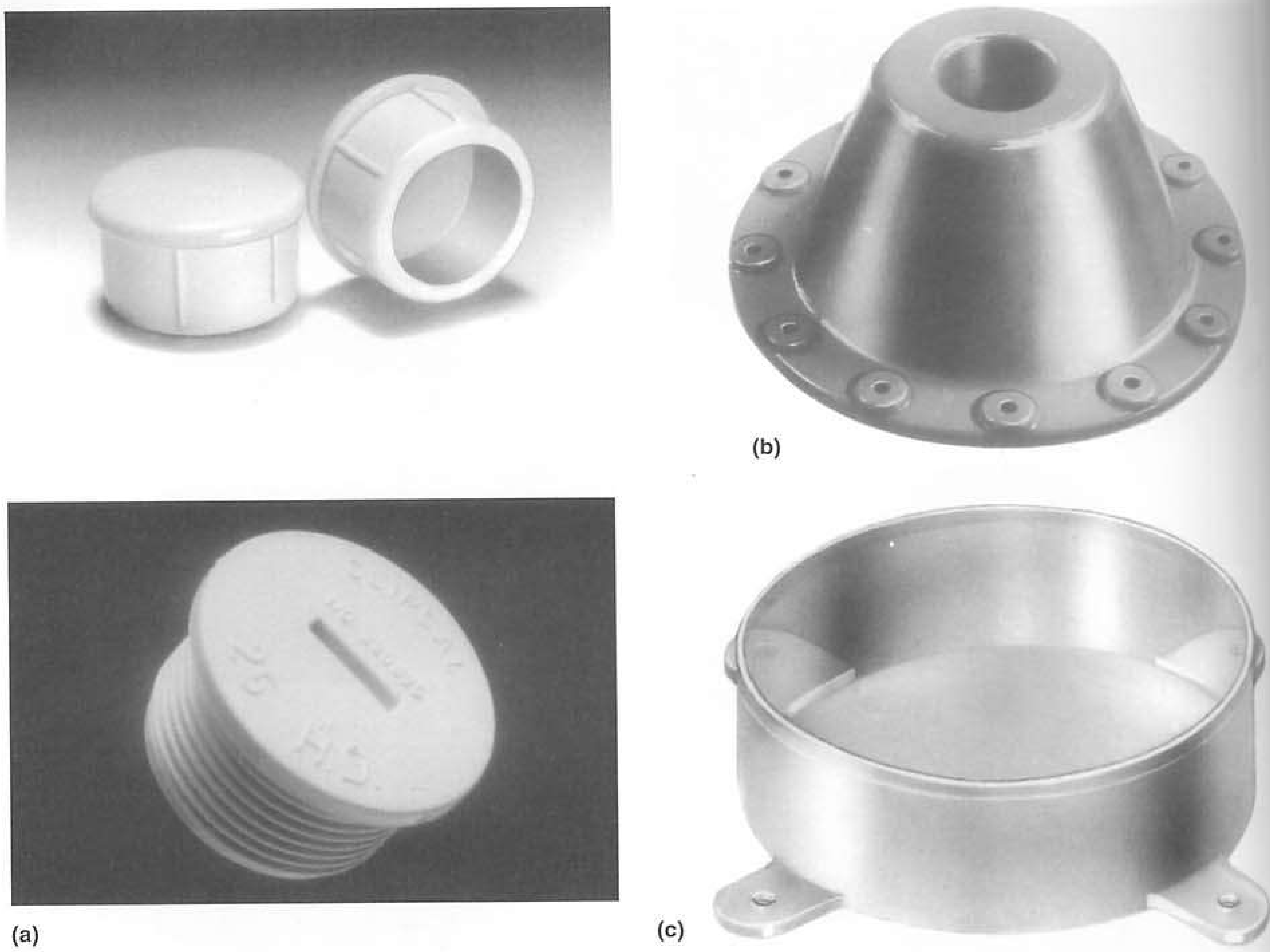


Fig. 5.22 **(a)** *Conduit plugs, screwed and plain;* **(b)** *Conduit-locating flange;* **(c)** *Disposable round junction-box lid* GERARD INDUSTRIES

The use of deep-type junction boxes in concrete jobs is mentioned in Chapter 9 and in section 5.2 of this chapter, but a variety of other junction boxes are available, some of which are shown in Figure 5.23.

The unique connection and junction-box system illustrated in Figure 5.24 does not require the use of adhesive or PVC solvents or threaded adaptors; conduits are simply pushed into position. The manufacturers

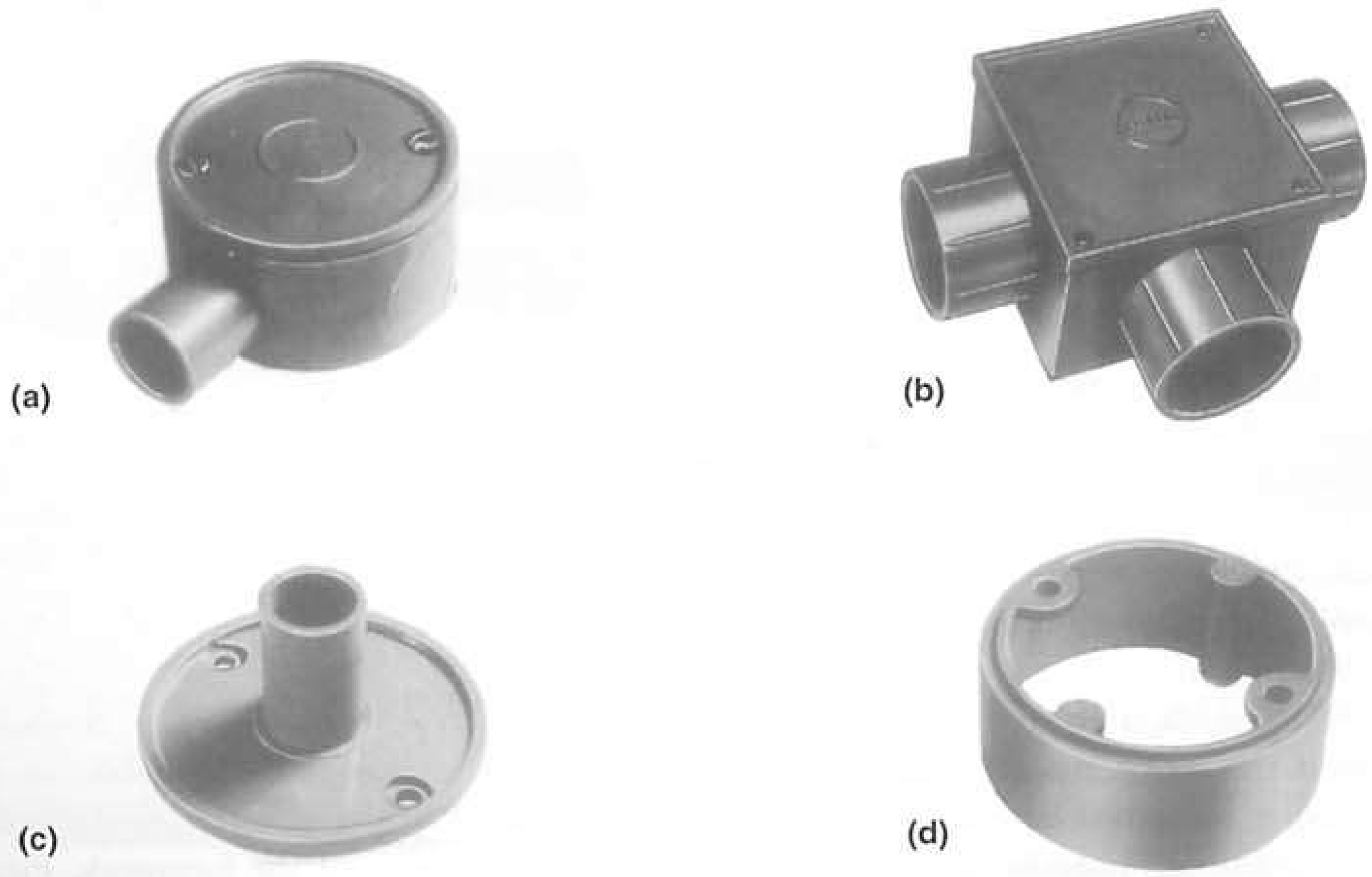


Fig. 5.23 **(a)** *One-way round PVC junction box;* **(b)** *Three-way square PVC junction box;* **(c)** *Round PVC junction-box take-off plate;* **(d)** *Round PVC junction-box extension ring* GERARD INDUSTRIES

5.4 Accessories for special installations

There are many situations and environments in wiring that require special treatment and accessories designed for a specific application. Typical of this category are situations where water or steam is continually present, high-temperature environments, situations where fires or explosions could occur, refrigeration chambers and high-voltage installations.

You must realise that the wiring methods and accessories acceptable and safe for general wiring are not necessarily suitable for these special installations. Therefore, should one of these situations arise, the logical approach is to seek specialist advice, study the relevant Rules of *Sections 6* and *9* of AS 3000 and, if a special code applies, study this also; for example, there is a code for installations in caravans and caravan parks, a refrigeration code, a lift code and others.

Manufacturers' catalogues may also be consulted for suitable accessories and advice. As examples of the differences in accessory design for these situations, study Figures 5.27, 5.28 and 5.29.

Damp or wet situations, for example where exposed to the weather, need accessories described by manufacturers as 'weatherproof' or 'weather protected'. These are broad terms; the International Protection (IP) rating of an accessory more accurately describes the protection it provides. Refer to the IP ratings chart provided in Chapter 19 (Volume 2).

Conditions of high temperature require special accessories and wiring methods; mineral-insulated metal-sheathed (MIMS) cables and accessories are typical of

Fig. 5.27(a) *Rigid PVC 'weatherproof' IP23 box suitable for mounting standard accessories such as socket outlets* GERARD INDUSTRIES

Fig. 5.27(b) *'Weatherproof' IP66 socket outlet* WILCO PRODUCTS

Fig. 5.27(c) *'Weatherproof/hoseproof' IP56 switch and socket outlet designed on a modular system. Cases are PVC, lids polycarbonate* WILCO PRODUCTS

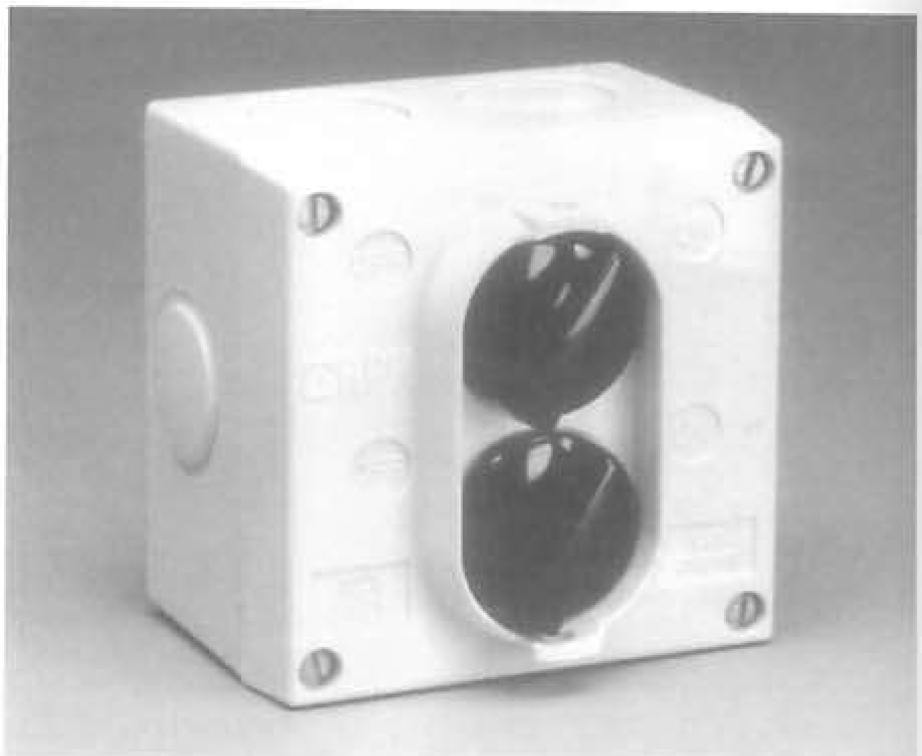


Fig. 5.27(d) *'Weatherproof' IP56 PVC switch* HPM INDUSTRIES

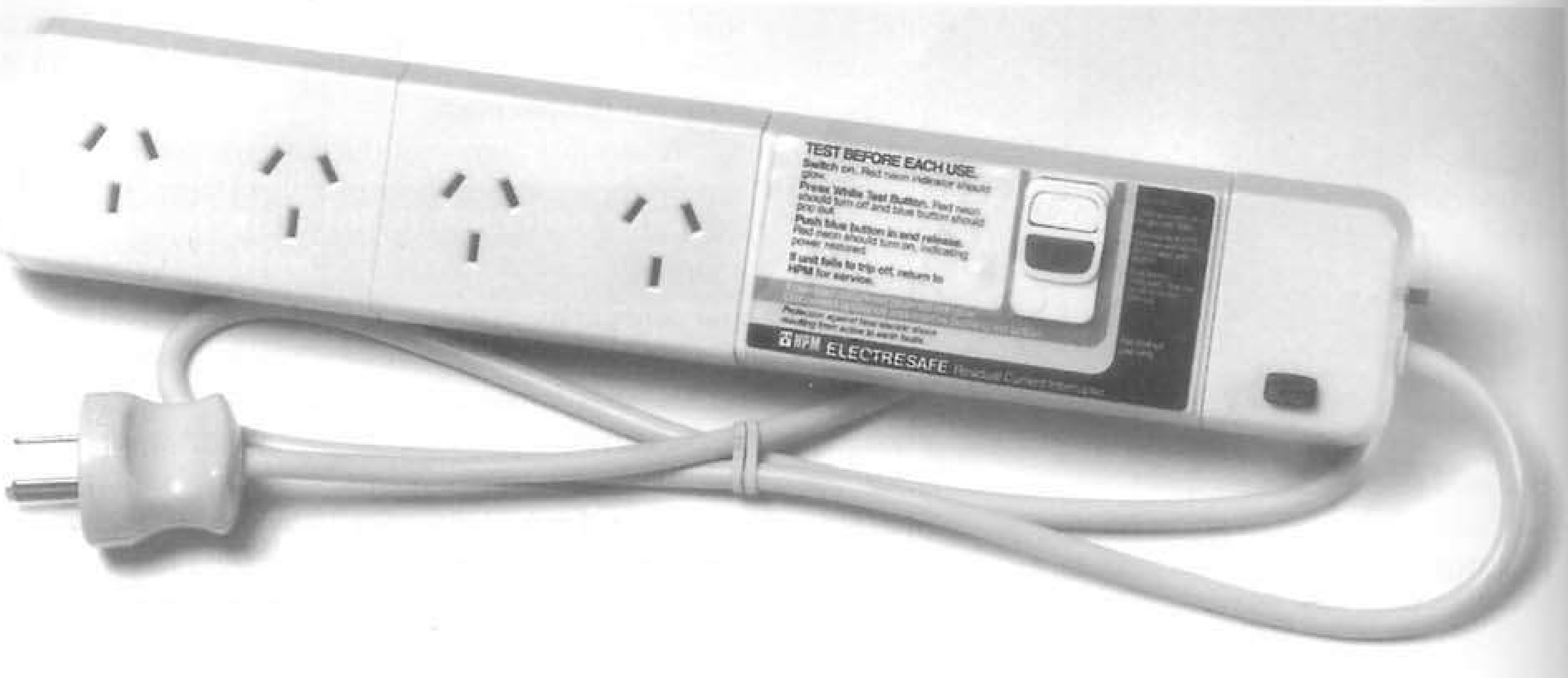


Fig. 5.32(d) *Portable powerboard with build-in RCD* HPM INDUSTRIES

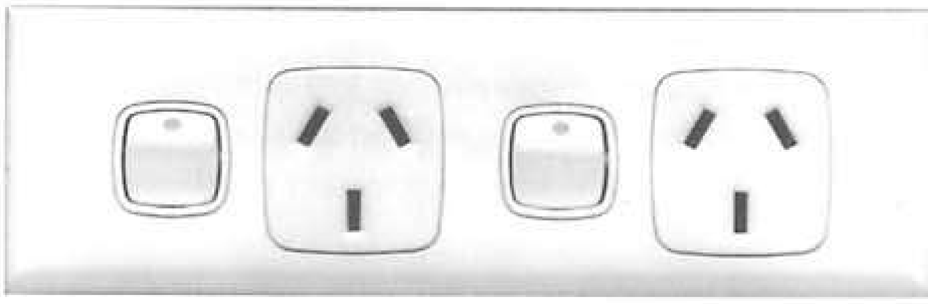


Fig. 5.32(e) *Twin skirting socket outlet* GERARD INDUSTRIES

domestic and commercial use. The result is a variety of design features as regards both appearance and utility, and a suitable type may be selected from a large range for practically any normal application. White accessories are usually selected by consumers, but coloured accessories are available if required. The two common current ratings are 10 A and 15 A, but a 20 A switch–socket combination is available, and control may be either single- or double-pole manual switching or by switching automatically when the plug is inserted.

Some models have safety shutters, which shield the active and neutral contacts and do not open until the earth pin (in some models the neutral pin) of the plug is inserted. Another safety feature on some models is a pilot light that indicates the 'on' position. Power outlets are made in single-gang, two-gang, three-gang and four-gang types on the one escutcheon plate. The single- and two-gang types may be provided with additional control switches; for example, the socket outlet in Figure 5.32(a) incorporates two independent one-way switches. Where personal protection from electric shock is required, the socket outlets illustrated in Figure 5.32(c) and (d) may be used. Each outlet has an inbuilt residual current device (RCD); and if it is the first point on a circuit of GPOs, all other points on the circuit will be protected (see Chapter 14, Volume 2).

A number of other special types of socket outlets are marketed, including:

- the timed outlet of Figure 5.33(a);
- the international shaver outlet of Figure 5.33(b);
- an outlet fitted with surge voltage protection (see Fig. 5.33(c));
- an outlet that will give protection against undervoltage to appliances connected to it; and
- a double-pole switched outlet that is switched by insertion and withdrawal of a plug (Fig. 5.36).

The timed socket outlet is fitted with a switch to override the timer if desired, and a number of different types are available for various timing periods. The international shaver outlet of Figure 5.33(b) accepts plug configurations from Europe, Britain, America, Canada, New Zealand and Australia (shavers only), and the three-pin outlet on the plate accepts appliances such as hairdryers and radios. It is available with or without an inbuilt RCD; the outlet illustrated is fitted with an RCD.

Most socket outlets are designed for flush mounting, but types made for surface mounting are available. In addition, special moulded-plastic mounting blocks may be used with flush fittings to enable surface mounting.

The clip-in surge filter mechanism shown in Figure 5.33(c) provides overvoltage protection for electronic appliances such as computers, television sets and fax machines. In the event of a voltage surge, metal varistors enclosed in the mechanism will absorb the surge at between 275 V and 710 V, thus protecting expensive electronic components in the appliances. An inbuilt neon, visible at the front of the outlet, indicates that the surge filter is operational.

The surge filter is **not** designed to absorb overvoltages that may be caused by lightning strikes.

A socket outlet that protects against **undervoltage** is available from the manufacturer of the surge filter described above. The device responds to a fall in voltage

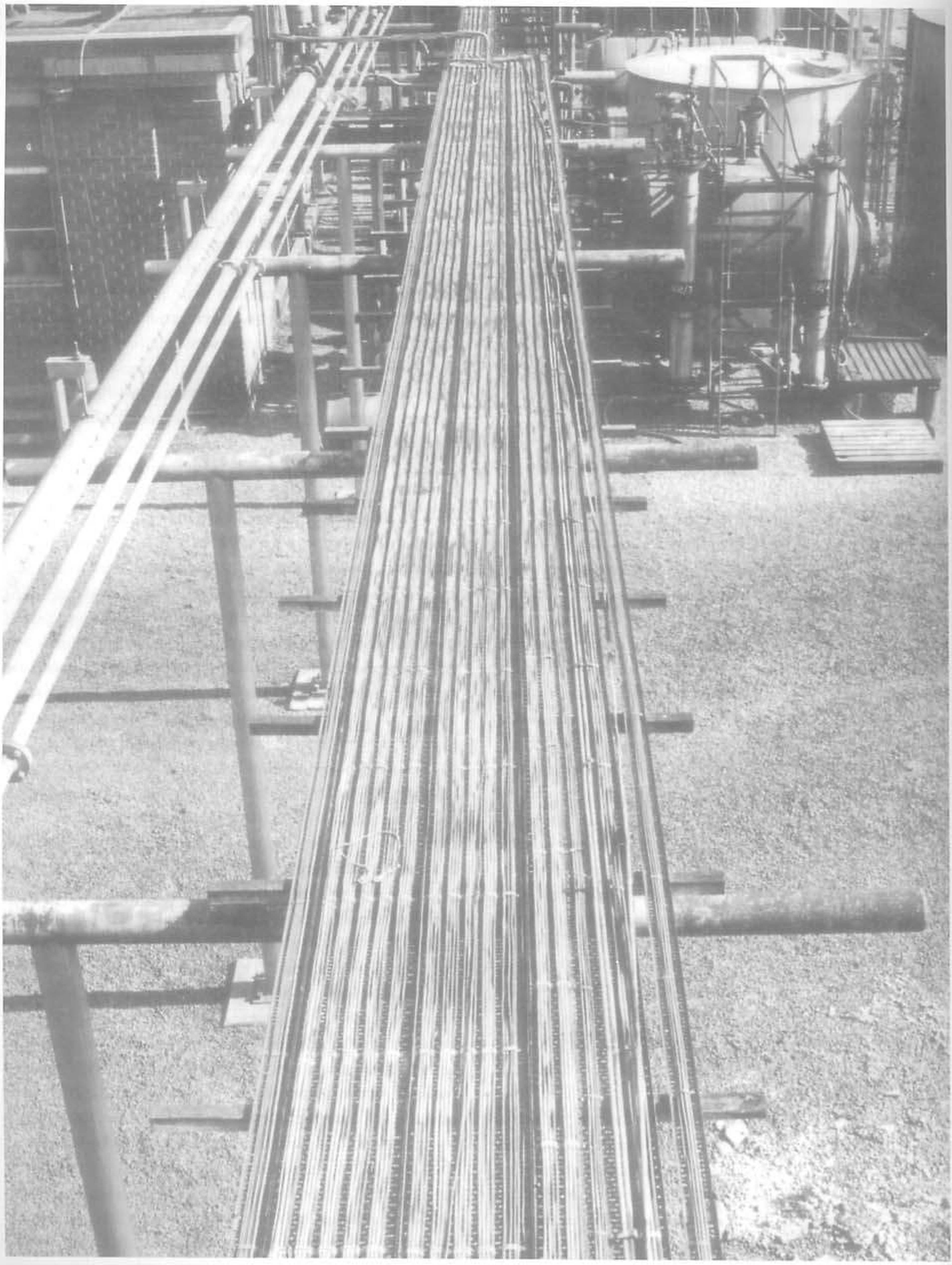


Fig. 10.4(a) *Section of MIMS cable wiring (two-, three- and four-core 660 V grade) to pump motors, lighting circuits and instruments at a sugar-refining plant* MM CABLES PYROTENAX

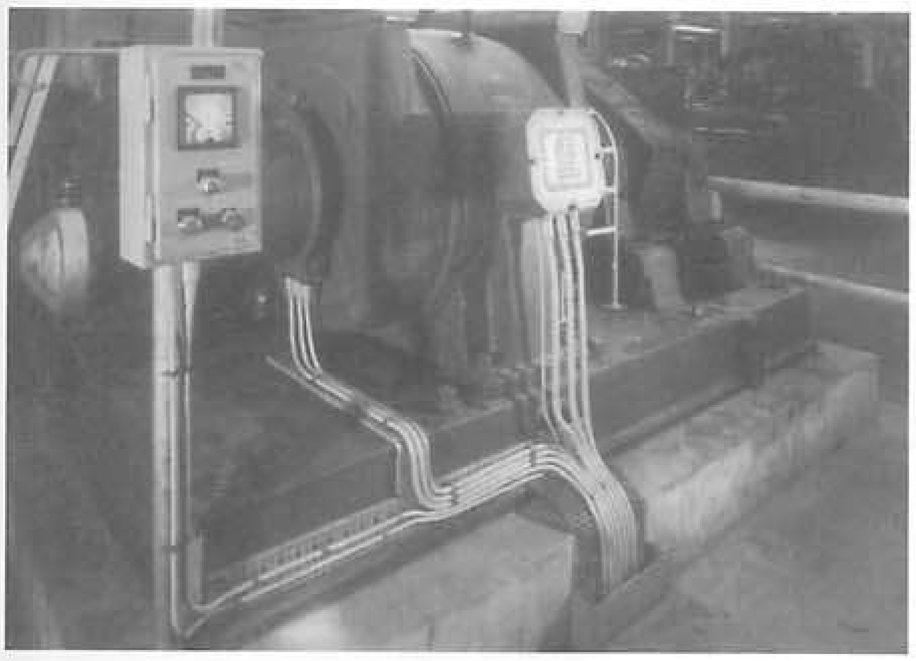


Fig. 10.4(b) *Wiring to a motor* MM CABLES PYROTENAX

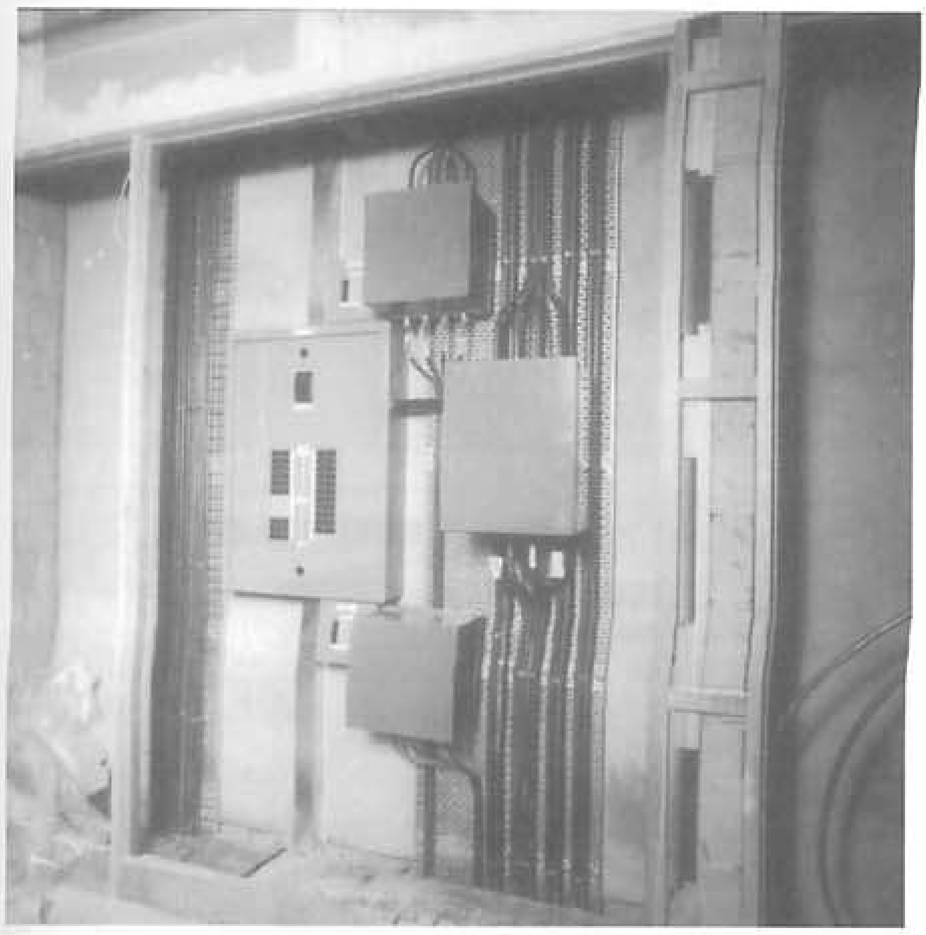


Fig. 10.5 *Wiring in a multistorey building showing tee-off from rising mains for the floor section* MM CABLES PYROTENAX

MIMS cable, and thousands of kilometres of the cable are used in marine work.

You will be able to think of many more applications where the peculiar properties of MIMS cable would be an advantage.

A rewire of a MIMS cable installation should never be necessary, as there is no doubt that, properly installed and under normal use and conditions, the wiring would outlast most of the other materials used in the building structure.

However, because of its relatively high initial cost compared with, say, a TPS cable wiring system, it is rarely used for the general wiring of domestic dwellings.

10.8 Installing and terminating MIMS cables

Installing the cable

The seamless annealed copper sheath that encloses the annealed copper conductors serves as a malleable conduit for installation purposes. Because of this, the cutting, threading, setting and installation of fittings such as bends and elbows are not required. The cable can be bent and manipulated by hand in all but the largest sizes; however, bending tools are available for large cables and for the smaller sizes, if necessary, for intricate work (see Fig. 10.6).

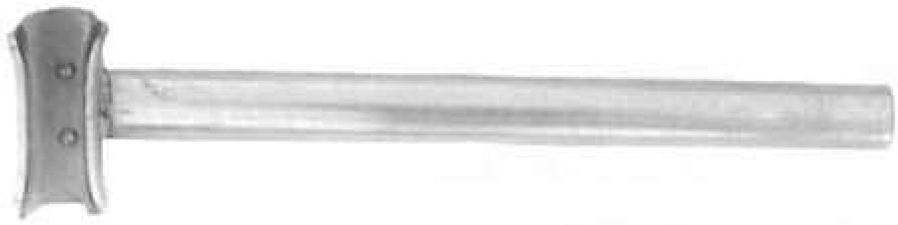


Fig. 10.6 *Bending lever* MM CABLES PYROTENAX

Bending radius should never be less than six times the diameter of the cable, and care should be exercised when forming bends or sets, as repeated bending will work-harden the copper and make it difficult to manipulate. If this should occur, it can be annealed in the usual manner by heating to cherry red and cooling. Unwanted bends or 'waves' may be removed by the use of a roller straightener, as shown in Figure 10.7; this tool is available in two sizes to cover the normal range of cables available.

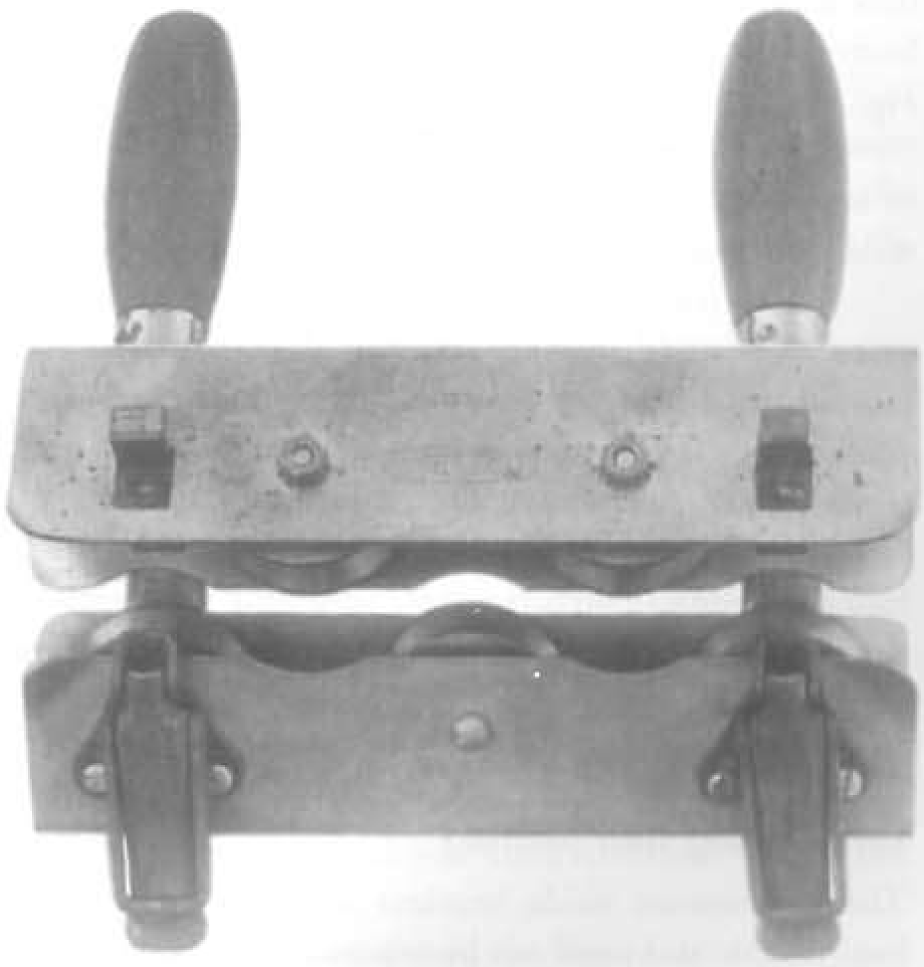


Fig. 10.7 *Roller straightener* MM CABLES PYROTENAX

contours. It is corrosion-resistant and is unaffected by chemically aggressive soils. It is easily distinguishable as an electrical conduit, because the standard colour is orange to differentiate it from telecommunications, gas and water services. It is often used above ground to provide heavy-duty mechanical protection. In this case it must be painted to protect it from ultraviolet light.

HFT conduit

The letters 'HFT' depict the three most important properties of a non-metallic conduit composed of a special plastic alloy: that is, halogen-free, fire-resistant and temperature-stable. Toxic or corrosive gases are not released in the event of fire, and conduit and fittings do not support combustion, self-extinguishing within 10 seconds. HFT conduit and fittings have an operating range claimed by the manufacturer to be between −40°C and +140°C, whereas PVC conduit is restricted to the range −15°C to +60°C.

HFT conduit is supplied in 4 m lengths in sizes 20, 25 and 32 mm outside diameter and has a wall thickness the same as heavy-duty rigid PVC. Standard colour is black.

Flexible metal conduit

Flexible metal conduit made from interlocked spirals of pressed metal is not normally used as a complete wiring system, but it is used in positions where movement could occur, for example to join a screwed conduit onto a motor where adjustment of the motor position is required.

Other types of flexible metal conduit are available for various applications. For example, there is an oil-resistant liquid-tight conduit manufactured with a heavy-duty PVC outer covering; this conduit was developed for applications such as machine tools operating in an environment where oil and grease are predominant, and will operate in the range −20°C to +105°C.

Flexible PVC conduit

Flexible thermoplastic conduit has virtually superseded flexible metal conduit in similar applications, for example in situations where flexibility is essential to take up movement due to vibration of a permanently wired machine or appliance, or where an appliance is required to be moved to provide access for service without disconnecting the appliance from the supply (see Fig. 9.3).

A corrugated type of PVC conduit that is pliable (not flexible) may be used for applications similar to those illustrated in Figure 9.2. It can be bent by hand to follow complicated curves and retains its shape after bending. The bore has smooth rounded corrugations to facilitate the drawing in of cables, and the conduit is mechanically robust. Both medium- and heavy-duty conduits are available in 20, 25 and 32 mm nominal (outside diameter) sizes, medium-duty normally being

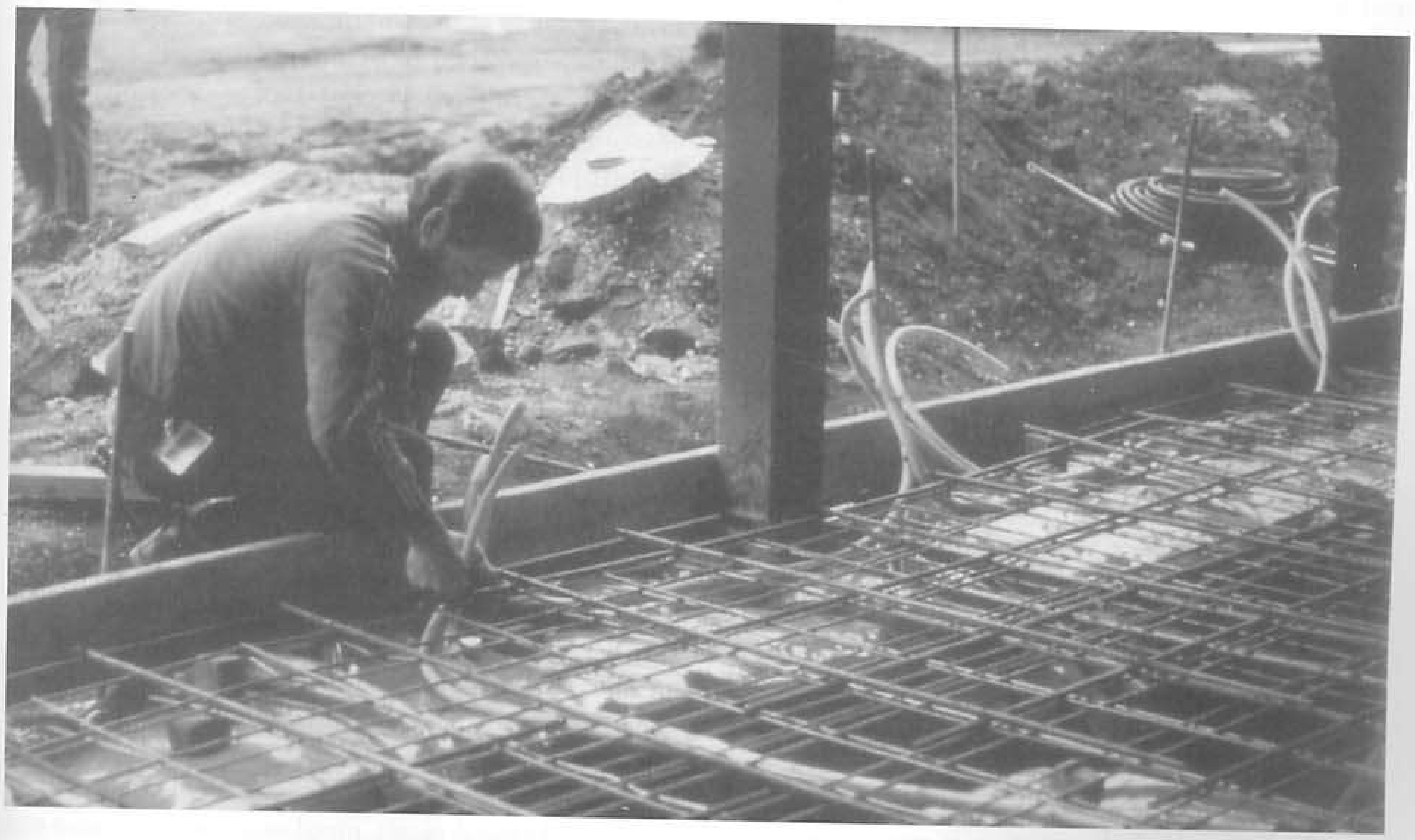


Fig. 9.2 *Installing corrugated PVC conduit in a concrete pour* GERARD INDUSTRIES

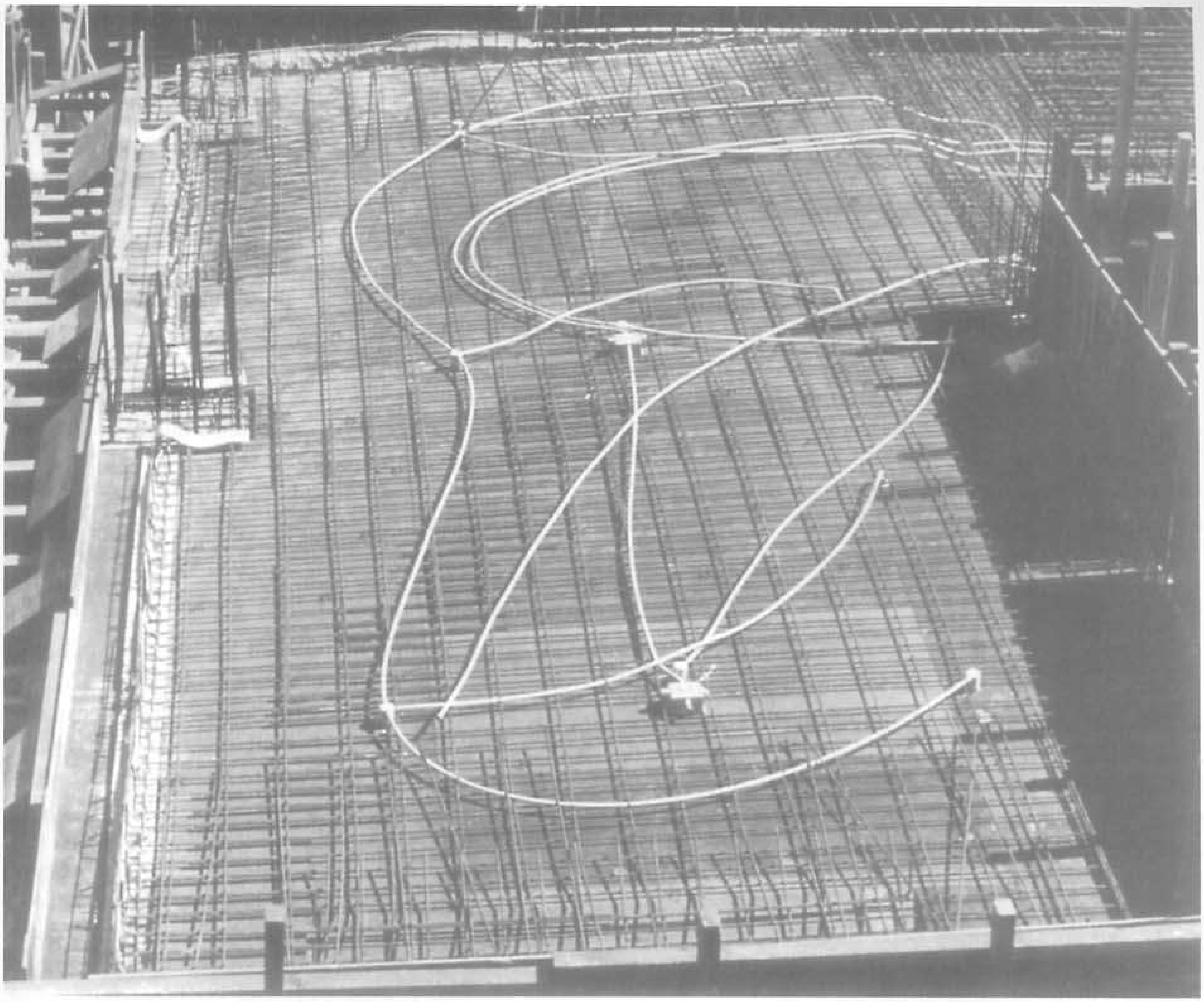


Fig. 9.16 *Installation of conduit in a concrete slab, prior to the pour*

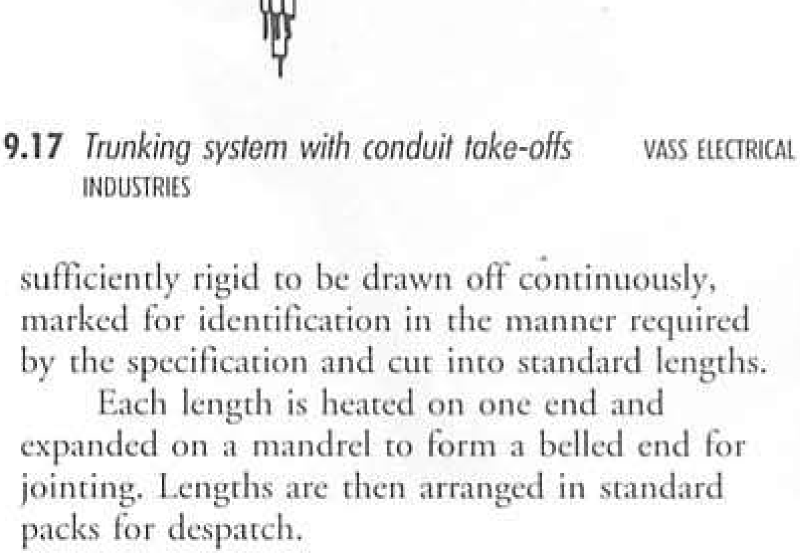


Fig. 9.17 *Trunking system with conduit take-offs* VASS ELECTRICAL INDUSTRIES

sufficiently rigid to be drawn off continuously, marked for identification in the manner required by the specification and cut into standard lengths.

Each length is heated on one end and expanded on a mandrel to form a belled end for jointing. Lengths are then arranged in standard packs for despatch.

Standard unit lengths of rigid PVC conduit are 4 m, and one end of the conduit is belled for easy joining, thus eliminating the need for a coupling when joining. The range of standard nominal sizes available is 16 mm to 50 mm for light-duty and 20 mm to 150 mm for heavy-duty rigid PVC conduit.

The conduit is much lighter and more flexible than steel, has relatively poor mechanical strength, and must be supported at intervals not exceeding 1 m (see *Clause 3.28.4.3*).

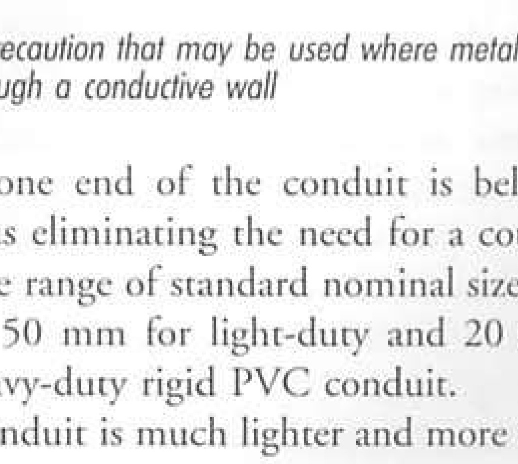


Fig. 9.18 *A precaution that may be used where metal conduit passes through a conductive wall*

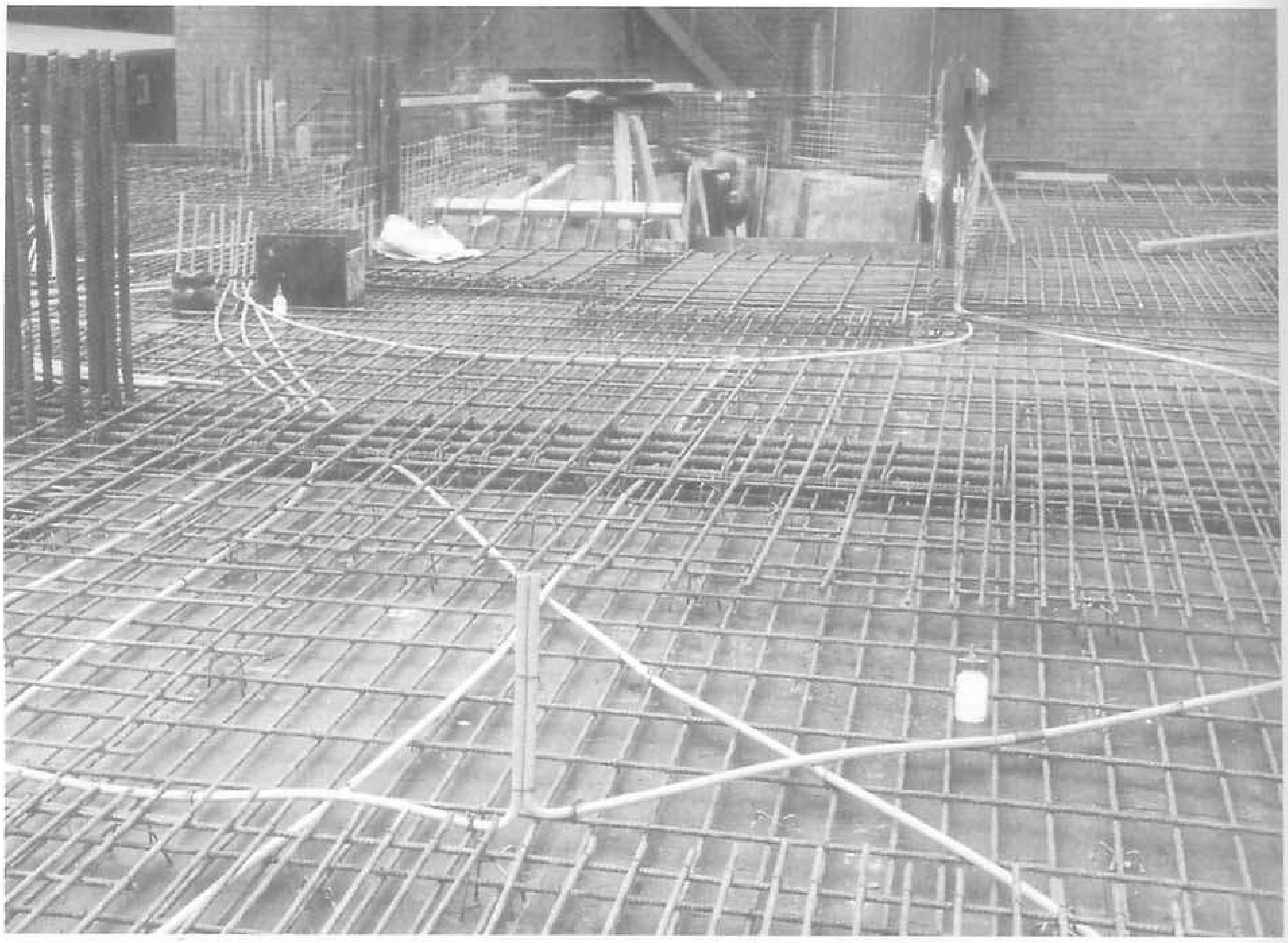


Fig. 9.22 *PVC conduit work in a high-rise commercial building*

Clause 5.4.4.2(b). Luminaires and accessories such as brackets, rigid pendants, switches and enclosures are considered as being effectively earthed if they form an integral part of the screwed conduit run. *Clause 5.4.4.2(c)* specifies the conditions.

In most cases, appliances are directly earthed by an insulated earthing conductor that is enclosed in the same conduit as the associated live conductors. However, metallic conduits, tubes, pipes, troughing and similar metallic enclosures may be used as an earthing medium for equipment as long as the conditions of *Clause 5.4.4.2* are fulfilled.

It is mandatory that the cable colour for an earthing conductor be green and yellow, as specified in *Clause 3.2.2.1*; however, note the exceptions listed. Green, yellow and combinations of green and yellow are prohibited as distinguishing colours for any other cable.

Colour coding for cables other than earth wires and insulated live consumers' mains is not compulsory unless the local inspecting authority requires it, but colour coding reduces mistakes when connecting up, often saves a lot of testing to identify cables, and speeds maintenance and repair work. The recommended colours for conductors other than earthing conductors are:

- black for neutral or middle wire;
- colours other than yellow, black, green, or green and yellow for actives and switch wires (for three-phase wiring, red, white and blue are commonly used for actives).

In single-phase circuits a suitable colour coding is red for actives, black for neutral and a distinguishing colour such as white for switch lines. The adoption of a colour code saves time and mistakes.

Number of cables in a conduit

When considering the number of cables to be installed in a given size conduit, the tables of *Appendix E* of AS 3000 may be used to determine the maximum number of cables recommended. The following relevant points should be kept in mind when using the tables.

Bore area

The number of cables that a conduit may accommodate is governed by its internal cross-sectional area (CSA) or 'bore area'. This available bore area may be different for conduits of the same size classification, and because of this it is most important that reference be made to the appropriate tables when using *Appendix E* of AS 3000. For example, the bore area of 20 mm light-duty PVC