fig. 1, to make each aid the other, was applied to meet the emergency; but this is limited to the upper parts of the walls.

Abutting struts from opposite walls, occurring at intervals only, leave the intermediate portions of the walls exposed to pressure from behind without support, unless these intermediate portions are so disposed as to communicate the pressure upon them to the struts. Hence a common retaining wall, abutted at intervals, would require these intervals to be more or less distant, in proportion to the strength of the wall between them. Instead, therefore, of a continuous wall on each side of the cutting, buttress walls should be placed at intervals, opposite to one another, and strutted apart at their toes by an inverted arch (as in fig. 2); and above, at a height sufficient for whatever traffic the cutting is to accommodate, by a built beam of brickwork, in vertical courses, supported on an arch, and prevented from rising under the pressure by an invert upon it, as in fig. 3. This built beam will then be, as it were, a piece of walling turned down on its vertical transverse section, and will resist any pressure brought upon it through the buttress walls, to the full extent of the power of such a wall built vertically to bear weight laid upon its summit; the pressure would be applied in the line of the greatest power of resistance, and there would be no tendency to yield, except to a crushing force. Let such transverse buttress walls, so strutted apart, with the road between them, be the springing walls of longitudinal counter-arched retaining walls, which, being built vertically and in horizontal courses, but arched in plan, against the ground to be retained, will carry all the force exerted against them to their springing walls, and the springing walls or buttresses will communicate, through the struts, the power of resistance of each side to the other, and thus insure the security of both.

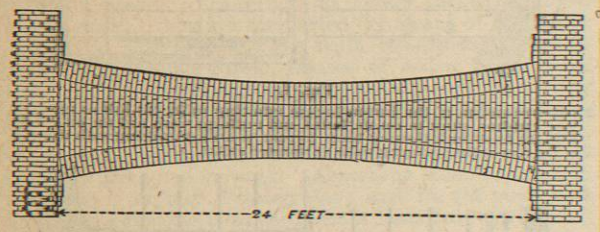

Fig. 3.—Built abutting Beams.

This arrangement may be carried to any extent in height, by repeating the abutting beam or strut at such intervals as the thrust to be resisted and the strength of the buttress springing-walls may require.

To constructions thus arranged, any requisite power may be given, by altering the quantity of materials in each part, —the length of the buttresses transversely of the cutting, the number of struts to each pair of buttresses, or the length of the compartments. The thickness of the buttresses should be in proportion to their height and length, and their length should be in proportion to the flatness and weight of the struts with their arches, and to the space in height between any two of them, as well as to the magnitude of the thrust brought to them by the counter-arched retaining walls. The inverted arch below and the built beam above must, of course, have sufficient substance to enable them to resist, without yielding in any direction, the pressure brought to them through the buttresses; and the retaining walls themselves must have substance given to them according to their height, to the pressure they are liable to receive from behind, to the length of the compartments, and to the extent of their flexure;—subject, of course, as to all these, to the nature of the materials, workmanship, and mode of structure.

The positive strength which such constructions should possess depends much, of course, upon the nature of the soil, and its susceptibility of being affected by external influences; but it depends, even in a greater degree, upon the manner in which the constructions can be applied to the ground they are intended to retain. A very slight power will retain at rest a body which the exertion of great force could not stop if once in motion, and a half-brick counter-arch, set in close contact with undisturbed ground, would hold safely up what three times the substance would not stop if there were space and opportunity for motion between the ground and the brickwork. It is impossible, therefore, to state precisely what is the least strength which the retaining constructions must have, but there can be no question that too much strength is better than too little, and it is generally cheaper to pay in materials than in labour to save materials.

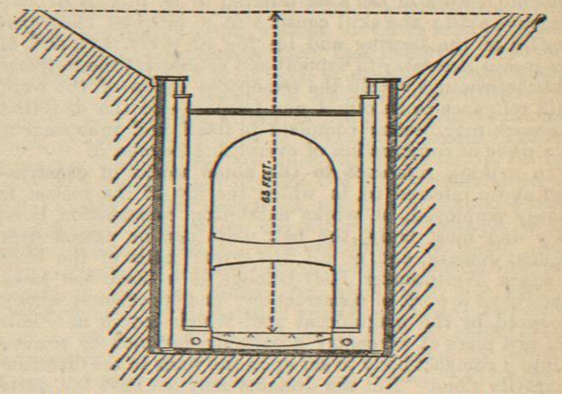

Fig. 4.—Transverse section through the centre of a Bay.

An example of a cutting. The diagrams, figs. 4 and 5, represent a cutting 65 feet deep to the level of the rails. It is assumed that the ground at the top may stand for the first 15 feet at less than 2 to 1, and that it may, therefore, be cheaper to run out to that depth with slopes, leaving 50 feet from the rails, or about 52 feet in all, to be retained. As the bricklayer may follow up the excavator with bay after bay, his work lying mostly on the side and out of the way of the excavator, the latter would run out the spoil without interruption, his work being benched onwards and shored as he proceeded. As every compartment, with its buttresses, invert, abutting beams, and counter-arches is complete in itself, the ground being backed against the counter-arches as the work rises, the shoring would come out, and be sent on for use on the forward benches. The invert may be turned upon footings in half-brick rings, to get the largest quantity of solid resisting matter in the curved line. At a height from the surface of the rails sufficient for headway—assumed at 14 feet 6 inches—a 14-inch bonded arch is turned from buttress to buttress, springing from skewbacks on corbelled courses. Upon the back of this arch the abutting beam is built of brick on end and edge, bonded as a wall, with beds vertical and widening over the haunches of the discharging arch and under the similar inverted arch turned upon it; so that although the beam be in the centre but 21 inches deep, it presents an abutment at each end of three times that depth. The object of the invert over the abutting beam is to stiffen it, and to bring down and distribute the weight and pressure from the buttresses more effectually. The built beam, and its sustaining and stiffening arches,

should be composed of particularly well-formed bricks of really good quality, set in cement or in some quick-setting mortar, that there may be no yielding to the pressure which must be immediately thrown upon this part of the construction. Another built beam, of greater depth, because of the absence of any inverted arch to stiffen it, is thrown across over the back of a semicircular arch, with its abutting ends extended in like manner.

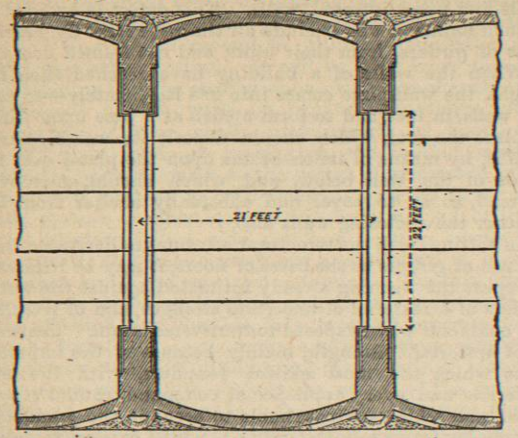

Fig. 5.—Plan at twice the scale of the Section (fig. 4).

Drains. To relieve the work from water, a drain being run along over the middle of the inverts, or side-drains being passed by ring culverts through the buttresses, drain-shafts are carried up at the backs of the buttresses against the springings of the counter-arches, to within a few feet of the surface. These shafts, being steened with open joints at intervals to admit drainage water and communicating with the drains below, prevent the possibility of water lodging about the backs of the counter-arches, or even in the ground itself. The drain shafts should be semi-domed with bricks set dry and covered in, and the walls also backed up with good clean gravel, through which the surface water may percolate and pass freely down to the shafts.

The constructions are assumed to be of brickwork, for the obvious reason that the cases supposed being clay cuttings, brick is the material which would be most economical. But if masonry be cheaper, it may of course be used with the same effect. Where a cutting intersects loose beds of laminated stone, and particularly strata inclined to the horizon, so as to be unsafe with the ordinary slopes, such constructions are available; and in cases where the sides of the cutting will stand vertically or nearly so, as in chalk, it may be useful to apply similar constructions, though of slighter character, to check the separation and fall of masses from the precipitous sides. It is obvious, too, that these constructions present the means of security, when the stratum forming the base of any cutting is too weak to bear the weights of slopes, or of retained sides, without rising between them. Sheet-piling may be driven to any depth along the backs of the counter-arched walls so as to be retained at the head by the walls; and thus in effect the walls would be carried down to a safe depth, even through the weak stratum; whereas such piling at the toes of slopes is commonly found to be almost if not wholly useless, for the want of a stay to the head.

The ignitibility of timber, and the rapidity with which it burns when placed in circumstances so favourable to that effect as by its disposition in an erected building, have led to its prohibition for the purposes of the main enclosures of houses and buildings generally, in London, and in many of the larger provincial towns. It is possible, however, so to protect timber employed in the enclosures and for the internal partitions and floors of buildings as to render mere dwelling-houses practically incombustible. Whilst, however, the liability of timber to take fire and to burn may in a great measure be counteracted, and notwithstanding that this material combines the advantage of economy with security, stone and brick are undoubtedly better adapted for the main structure of a building. Brick or stone, or brick and stone together, with a setting material, ought to be employed, but in such manner only as to be free from dependence upon other and less trustworthy materials. The most perfect erections as buildings are those in the composition of which this principle has been understood and fairly practised. If adventitious aid be given to brick or stone walls by foreign materials, the materials ought to be at the least harmless. Iron in bulk is not a proper substance to incorporate with walls because of its great expansibility by heat; but iron used in thin laminæ, as hoop-iron laid in walls in the bed-joints of the brick or stone, cannot be productive of any bad consequences, while it is most beneficial in that form as a tie to the structure. **Hoop-iron.**

Bricks and stone. Bricks come ready shaped to the hands of the workman in a form the best adapted for the arrangement in the construction of a wall which, under the designation of bond, gives it such a degree of consistency that a weight placed upon the top is carried by the wall in every part throughout its whole thickness, and throughout a greater or less proportion of the length according to the height of the wall. Stone, on the other hand, comes to the workman without regular form; and with skill on his part to dispose and arrange the materials, good erections may be produced of rubble; for although the thickness of which walls may be built of rubble with safety will depend in a great degree upon the quality of the mortar, much depends also on the skill of the workman in bedding and bonding the stones. Under any circumstances, however, a wall so composed cannot safely be charged with heavy weights, or be exposed to the vibrating action of floors, until the mortar shall have indurated to some extent; whereas a wall of brickwork is secure by the horizontal bedding of the bricks, and by the effect of the transverse bond which the alternation of header and stretcher almost necessarily produces. Stone, again, may be dressed to any shape, and so as to mould it to every variety of construction with the smallest possible quantity of mortar or cement. From blocks with rough hammer-dressed parallel beds, up to the most complete and perfectly wrought parallelopipeds adapted to any arrangement of bond that may be best adapted to the structure, and with combinations of rudely formed and perfectly formed pieces of stone, walls may be built of stone of greater strength than the best brick can be made to yield, whilst stone walls are liable to be inferior in every respect to brick-built walls of ordinary quality.

Some combinations of the two kinds of materials have the effect, however, of making a better wall than could be produced by the main constituent in the form employed alone. A stone-rubble or pebble built wall is greatly improved by one or two bonding courses of brickwork at short intervals; and a brick wall is improved and adapted for a higher purpose by thorough courses, at intervals, of good stone, wrought to bed and joint truly; whilst on the other hand, a wall substantially of stone-rubble or pebble, and faced with brickwork, is essentially an unsound wall; and in like manner a brick wall faced with wrought stone is liable to be weaker than the brickwork would have been without the stone.

With regard to the thicknesses of the walls of buildings, it is generally considered that these should be governed by the height of the structure; but they ought not to be determined by that condition alone. Chimney-breasts, or other buttress-like projections, built up with a wall, and extending to more than the thickness of the wall, make it in fact stronger in its transverse section, and justify less general thickness in the body of the wall, whilst window and other openings in a wall leave piers which ought to be of greater thickness than the mere height would require. But all returns, indeed, whether as chimney-breasts or as cross walls, built and bonded with a wall, tend to render unnecessary the full thickness which the height might require; whilst, as just intimated, the omission of portions of a wall for door and window openings should be compensated for by additional substance to the parts which remain. Walls subjected to undue action, such as that arising from slight joists tailed into them, or that occasioned by inclined timbers, as under galleries in churches, chapels, and theatres, require to be of greater thickness than they otherwise would; whilst it is quite wonderful to what great heights brick walls may be built with safety, if they are well built, and exposed to no other action than direct vertical weight. When, indeed, such walls stand upon a sufficient foundation, direct vertical weight without motion is a means of security to the walls so long as the weight is reasonably within the power of resistance of the materials to crushing pressure. The object to be looked at, therefore—the walls being honestly built—is, as before remarked, to make the weight to be imposed upon any wall act upon its solids vertically and steadily.

Floors.

Floors upon girders, or framed to strong trimmers—the girders or the trimmer-joists running into and bearing upon the piers or solids of the walls—are far preferable to what are termed single floors, of which each joist runs into the wall. Girders as the basis of floors render plates in the walls wholly unnecessary, by depositing the weight in the right places, without requiring plates to carry it on from the weaker to the stronger places; and being of necessity stout and rigid, they form a fair tie and strut to the walls into which their bearing ends are tailed. Whether girders or trimmer-joists be employed for placing the weight of floors upon the walls of a building in the safest manner, the bearing timbers ought to be placed upon pieces of stone as templets built into the walls, and to be made to take a cog-hold of the templets, so as to enable them to tie and stay the walls by means of the cogs. It is by means of the girder bearing upon the solids of the walls, though with bad carpentry, that the French are able to carry up their soft, coursed-rubble, stone walls to heights that would certainly be unsafe if the walls were seamed with wooden plates, and shaken by floors of single joist; such, for instance, as a wall of a total height of say 85 feet, with a thickness of 18 English inches on the ground-floor and through six stories, or about 65 feet, and finished by a gable,—the basement being vaulted with walls about 20 inches thick. It is by means of the solidity given to the floors by the girders, and the solid bearings which the girders obtain, that the floors are able to carry the dead weight of matter which renders them practically fireproof, as described below, in addition to the moving weights to which the floors of buildings are necessarily exposed in use. We can and do frame floors most effectively by carpentry alone; whereas the French do the work so badly, that no important bearing is, or indeed may be, trusted by them to the framed joint—dog-nailed stirrup straps of iron being always brought in aid. But the common practice in England is to use single or unframed floors, which carry the weight and the vibration to which floors are exposed into the walls, over voids as well as over solids; while the French frame their floors to or upon girders, by means of which the floors are brought to bear upon the solids of the walls. The walls are thus not only less exposed to vibratory action, but are both tied together and strutted apart with better effect by the stout girders stiffened by joists than by joists which themselves require some foreign aid to stiffen them. Moreover, single floors of joists, unless trimmed at frequent intervals, when, indeed, they may be termed half-framed, are supposed to require plates of timber laid along the inside faces of outer walls and upon internal walls. This defect is avoided by French builders, who exclude all timber, except the bearing ends of girders, from their walls, and use framed floors.

When the walls of a building have reached their full height, the wall-plate comes into use legitimately—to cope the walls, in fact, and to form a curb as a base upon which to place the roof, which should deposit its weight, nevertheless, by means of its tie-beams upon the plates over the solids of the wall below, and which should, moreover, oversail, so as to cover and effectually shelter from the weather the enclosing walls also.

Cast-iron girders.

In setting forth the structural advantages derivable from the use of girders as the bases of floors, it may be necessary to repeat the warning already intimated against the use of girders of a material of uncertain strength, and of treacherous character when exposed to transverse strain. Cast-iron is of uncertain strength, mainly because of the imperfections which the most skilful founders, with the best materials and every appliance at command, cannot always avoid, and which are most liable to occur in the production of complex forms in long lengths; whilst careless founding and rapid cooling are contingencies connected with the production of cast-iron girders—which are necessarily long and complex castings. Cast-iron is treacherous, inasmuch as it is brittle and liable to be startled into fracture by impact trifling when compared with what it may have borne safely as a dead-weight. Proving long metal castings by straining them upon their transverse section does but aggravate imperfections, and leave the casting weaker; whilst no dead-weight proof is proof against blows or other action inducing vibration. It is only under circumstances which do not admit of concussive action upon the beam, or which prevent it from vibrating under any shock that may reach it, that cast-iron can be safely used in beams of long lengths to carry heavy weights, without some appliance to mitigate, at least, the imperfections which this substance exhibits. The application of wrought iron tension bars as soles to beams and girders of cast-iron would prevent the most serious consequences from attending the failure of the casting, if the beam were also prevented by binders, or by other sufficient means, from turning round when the blow produces an oblique fracture. Wrought iron girders can be and are now extensively used to carry floors, partitions, and even walls with safety.

Tension bars.

Foundations.

Inasmuch as some soils are liable to change in form, expanding and contracting under meteorological influences, as clays which swell when wetted and shrink when dried, concrete foundations are commonly interposed upon such soils to protect the building from derangement from this cause; or rather, for that purpose walls of the cheaper material, concrete, instead of the more expensive brick or stone structure, are brought up from a level sufficiently below the ordinary surface of the ground. When concrete is used to obviate the tendency of the soil to yield to pressure, expanse or extent of base is required; and the concrete, being widely spread, should therefore be deep or thick as a layer, only with reference to its own power of transmitting to the ground the weight of the wall to be built upon it, without breaking across or being crushed. But when concrete is used as a substitute for a wall, in carrying a wall down to a low level, it is in fact a wall, wide only in proportion to its comparative weakness in the

absence of manipulated bond in its construction, and encased by the soil within which it is placed.

The foundation of a building of ordinary weight is, for the most part, sufficiently provided for by applying what are technically termed footings to the walls. The reason for a footing is, that the wall obtains thereby a bearing upon a breadth of ground so much greater than its own width or thickness above the footing, as to compensate for the difference between the power of resisting pressure of the wall and of the ground or ultimate foundation upon which the wall is to rest. It will be clear from this, that if a building is to be erected upon rock as hard as the main constituent of the walls, no expanded footings will be necessary; if upon chalk, upon strong or upon weak gravel, upon sand, or upon clay, the footing must be expanded with reference to the power of resistance of the stratum to be used as a foundation; whilst in or upon made ground, or other loose and badly combined or imperfectly resisting soil, a solid platform bearing evenly over the ground, and wide enough not to sink into it, becomes necessary under the constructed footing. For this purpose the easiest, the most familiar, and, for most purposes, the most effectual and durable, is a layer of concrete, which may be formed so as to cover a surface large enough to obtain from the most yielding soil the amount of resistance to pressure required to support the weight of the intended building. It will be evident that upon a concrete foundation a footing or expanded base may or may not be required to a wall, according to the hardness of the concrete and the kind of wall to be built; but it is perhaps better to give the footing to the wall than to wait for the sufficient induration of the concrete to enable the wall to do without a footing; and better still, to lay the concrete of such height only with reference to the spread or extent of base beyond the toes of the footing, as the gravel of which the concrete is made would stand at in an uncombined condition. Concrete, indeed, is at all times more safely to be regarded as a substance to be placed as a layer, than as a substance to be set up as a wall; for although excellent erections as walls may be made of concrete—as erections in the same form may be made of tempered clay or of pisé-work—neither concrete nor tempered clay is to be regarded as a proper substance with which to form the lofty walls of buildings in towns. The use of lime concrete involves walls of a considerable thickness; Portland cement concrete, a stronger material and having the property of hardening rapidly, is more commonly used for thin walls. Several patents have been taken for erecting buildings with concrete walls by the construction of troughs formed of frames and movable boards or shutters. But considerable doubt exists as to the extent to which such walls can be built, as many have cracked, proved leaky, and shown other faults; whilst much economy does not result except where the work is very plain and straightforward, where little is spent on subsequent finish, and where the materials can be obtained at very little cost either for themselves or for carriage.

Concrete.

Construction for Protection against Fire.—Houses seldom take fire from common accidents, such as occur to the lighter movable furniture and to drapery; but, for the most part, from the exposure of timber in or about the structure to the continued action of fire, or of heat capable sooner or later of inducing the combustion of timber; and as the source is most commonly in defective gas-piping, or in some stove, furnace, flue, pipe, or tube, for generating or for conveying heat, or for removing the products of combustion, much of the real danger to buildings from fire would be prevented by avoiding that degree of proximity of timber to all such things as can lead to its combustion. With a view to lessen the danger to which buildings with timber in their structure are exposed from fire, it will be well to consider how far the timber and wooden fittings commonly used may be necessary either to the stability of the buildings, or to the comfort and convenience of the inhabitants. But it is not our intention to describe here the various modes of fire-proof construction, but only to notice the principles upon which ordinary buildings may be rendered nearly incombustible. So long as danger of fire is brought to buildings through pipes and tubes, the necessity must be admitted of guarding the combustible materials used in buildings from any chance of becoming ignited. When heat is produced and passed through pipes in any manufactory, whether it be to act as power, or for drying or for warming, the fires used may be guarded, and the machinery which regulates the intensity of the heat to be transmitted may be under constant care; but even in such cases there can be no certainty that the heat shall not at some time arrive at the point of danger. But when heat is diffused throughout dwelling-houses by means of apparatus which is committed to persons unskilled in its use, and unconscious or careless of the danger which may arise from neglect, it seems impossible to lay down inflexible rules for distances from timber which shall render it safe from heated pipes. Twelve or fifteen inches may not be a greater distance than safety requires under some circumstances, whilst there are many cases in which the actual contact of such pipes with timber is hardly inconsistent with safety. When the air about heated bodies is not confined, as it would be within the timbers of an ordinary floor, a distance between the timber and the heated surface equal to the longest diameter of the tube or pipe will be found sufficient if the temperature of the pipe does not exceed that of boiling water. It is to be understood that a piece of wood will bear a powerful dead-heat upon its sides for an indefinite period without igniting, unless a transverse section of the fibre, as at or around a live knot, or where a branch had been lopped, present itself to the action. It is by the end that a piece of wood exposed to powerful heat most readily ignites. The gases evolved in the substance of the timber by the action of heat applied to its surface, expanding as they are evolved, are thrown out by the pores among the fibres at the ends, if the ends are near enough to the action to allow of this effect, with less power than may be enough to obtain vent for the inflammable gases laterally.

Buildings Acts.

The English Government, when it has legislated upon such matters, has generally confined itself to making provision that the enclosing walls of buildings should be formed of incombustible materials. In provisions regarding the least thicknesses of such walls, these were generally determined with reference to the height of the building, and to the area to be enclosed, as an indication of the probable lengths of the walls; and this both for the purpose of promoting safety of structure, and of checking the spread of fire from building to building. As, however, in most cases greater thickness is required in the side wall of an ordinary dwelling-house in a town to render its structure secure than is necessary to enable it to check the spreading of fire, such walls are frequently made of greater thickness than would be necessary to fulfil the objects which the Legislature has had in view, if the walls were not supposed to extend the whole length of the two longer sides of a parallelogram without intermediate cross or return walls. A solid, well-built brick wall, one brick or 9 inches thick, between two ordinary dwelling-houses of five or six squares in area each, will prevent the communication of fire through it from one to the other. But, in towns, ordinary dwelling-houses, which occupy each an area of five or six squares, are generally disposed in plan as parallelograms, having their opposite sides 18 or 20 feet, and 28 or 30 feet respectively in length, and are seldom carried up to less height than 35