Foundations

Foundation designs for straw bale buildings have been developed by going back to basics and thinking through how and why traditional designs worked. What's great about this approach is that it keeps things as simple and cost-effective as possible AND provides foundation solutions that are applicable to all buildings, not just straw bale ones.

All buildings need to have some sort of a foundation on which to build. This may simply be the natural foundation of the earth beneath, e.g. bedrock, gravelly soil, firm clay, etc., but in today's world we are more familiar with artificial foundations such as poured concrete strips and slabs. As the foundation has to carry the weight of the walls above it, and other loadings such as floors, furniture, roofs and even snow in winter, it is important to know what type of earth (or subsoil) is found on your building site. Different types of earth will be able to carry different weights. Gravelly soil, for instance, will carry much greater weight than soft clay. On the other hand, if you increase the surface area that bears the weight on soft clay – much like wearing snow shoes in the snow – even this can take the weight of a house. For a small building constructed of lightweight materials, there is obviously no need to build massive artificial foundations on any type of soil. Equally, for a heavy building built on what we call good bearing soil, there is also no need to use deep foundations. Almost all the buildings in the UK and Ireland that are more than 200 years old have natural foundations with little or no artificial ones. They often use larger stones at the base of the wall, making it slightly wider than the wall itself. In all cases, the builders removed the topsoil and dug down to something solid, and because they chose their building sites well, this was usually just below the topsoil.

There are hundreds of thousands of houses still lived in today that can be excavated by only 150mm (6") or so to find they are sitting on the ground itself, and yet they are completely sound and safe. Unfortunately, there are many misconceptions about foundations that are partly caused by the rise in popularity of cement and concrete. In some building colleges, students are taught that buildings can only have foundations made of concrete, despite the evidence to the contrary that surrounds us.

We use foundations to achieve a stable base that distributes the weight of whatever is built upon it over the ground beneath, to be sure that there is no unequal settlement throughout the building, to allow flexibility for the building to move over long periods of time as the ground itself moves, and to keep the inside of the building dry. In the past, natural materials were used to protect buildings; nowadays, manufactured ones are used, and they do not perform in the same way. So we also need to know the essential properties of materials in order to use them wisely.

At the base of the wall, foundations need to be designed so that:

- moisture from the earth cannot travel upwards through them
- rain bouncing from the ground is not able to pass through to the interior of the house
- any moisture that does find itself in the foundations can escape harmlessly to the earth or the exterior.

Traditional vs. modern designs

In the past, moisture was prevented from rising up from the earth by using non-porous building materials such as stone, e.g. slate, granite and some sandstones; or bricks, e.g. engineering bricks. These would be laid with lime or clay mortar to provide breathable joints, and coupled with good design above ground, e.g. double-skin walls with rubble infill. A natural slate damp-proof course would be used if the building material was porous or was expected to become so over time, e.g. some sandstones and brick.

Such materials and design were also used to prevent most driving rain from penetrating through to the inside of the walls. Moisture that did enter through small cracks or damage would be caught by the central rubble, filter down inside the wall and exit safely through the vapour-permeable joints once it had stopped raining. The main disadvantage with these types of walls, from a modern perspective, is that they do not provide insulation from the cold.

Problems can occur if modern materials have been used for renovation or repair that are not vapour-permeable, most commonly cement pointing, cement rendering and gypsum interior plaster. Often alterations have been made to the walls using poor workmanship and inappropriate choice of materials, e.g. a new window has been added using cement mortar, which has been allowed to fall down into the rubble infill, thus creating a bridge for damp to travel across into the internal skin of the walls.

Cement is used in buildings as a rigid, waterproof and strong material. Unfortunately, all these properties can contribute to damp problems. Firstly, its rigidity means that as the ground (and therefore the building) moves imperceptibly over time, the cement cracks because it is not flexible. Secondly, rain gets into a building through these cracks, filters down behind the stone or render finish, and builds up at the base of the wall because it cannot get out again as the cement mortar joints are waterproof. Thirdly, its strength means that it is often stronger than the brick or stone it is holding together and erosion of the weaker material happens at the interface between the two, causing the brick or stone to flake away and the cement pointing to remain intact. Over long periods of time, damp problems can occur.

The problems caused by inappropriate use of materials and design take years to become apparent, so it can be hard to accept that the damp at the bottom of your 150-year-old stone-and-lime kitchen wall is caused by the cement pointing the previous owner did 30 years ago coupled with the new gypsum you recently plastered the walls with.

Traditional building design accepted that rain and moisture could not be kept out of walls, but made sure that any that got in could escape safely to the outside, and also used flexible materials to prevent cracking. In the twentieth century we decided to build rigid waterproof buildings that moisture could not penetrate, but in practice this theory has never worked well because as soon as these materials crack, which they inevitably do because the ground is always moving, moisture gets in, filters downwards, and can't get out again. This is one of the main causes of damp in modern houses.

Using porous materials with a damp-proof course (dpc) on top shouldn't be a problem as long as there are no holes in the dpc – which is easier to ensure with slate than plastic. But if the dpc extends the whole width of the wall, e.g. on top of poured concrete foundations, then we have created a waterproof barrier that allows moisture to collect at the base of the wall just where we don't want it and prevents it from filtering downwards and safely out of the building. Modern buildings use a tray dpc with a slope towards the outside that directs any moisture at the base towards the outside wall not the inside.

The use of metal wall ties to hold the two wall skins together in cavity-wall construction also hold any cement mortar that is dropped into the cavity, a common occurrence when bricklayers are working fast and not caring too much about quality. This mortar then becomes a bridge for moisture to pass along to the inside of a building, and causes problems many years later.

Designing foundations

When thinking about designing foundations, the first thing to decide is whether the ground itself can provide us with a natural foundation. If it can, then there's absolutely no need to dig it away and create an artificial one. It has become the norm not to think about what the actual ground conditions are on a given building site, but to go for the lowest common denominator, a solution that will work in pretty much every situation, regardless of what the earth is doing for us, and dig 450mm- (18")-deep trenches and fill them full of wet concrete. In many cases, this is not necessary and thus creates an unjustified environmental impact that can also be expensive! But it does mean you don't have to think or have interesting discussions with your engineer or building inspector.

Stability; find out what your subsoil is

There are several ways you can find out what your subsoil is and if it's good bearing soil.

- Look at older houses in the area (pre-1900 and made without cement) and see what their foundations are made of. If they're quite shallow, you've almost certainly got good bearing soil. Not only that, but you can use the same foundation designs for your own house.
- Ask older people in the area, who might remember houses being built in their youth, what foundations were like then.
- Consult your building inspector, who should have a good local knowledge of older houses and subsoil in the area.
- Dig two or three pits about 800mm (31") deep in the place where your foundations will be, have a look at the profile of the soil, and take photographs of it to show your building inspector. Does it seem solid? Does any of it fall away? What's it made of – is it gravelly soil, stony or clayey?

An average two-storey straw bale house has a bearing weight of about $60kN/m^2$. This means that every square metre of foundation has to be able to hold up 60kN of weight. A typical brick and block cavity wall style house weighs about 50% more. The foundations of a typical straw bale house are 450mm (18") wide, which has the advantage of spreading the weight of the building over a wider surface area than most modern buildings.

The majority of building sites in the UK and Ireland are on good bearing soil, and this type of soil will easily take the weight of a straw bale house (and most other houses in fact, including stone ones). The types of soil where we need to think a bit more carefully about foundations are:

- heavy clay soils
- made up ground (i.e. you're not sure what it's made of because it isn't undisturbed subsoil)
- wet soils
- moving sand soils.

All other types of subsoil should be good bearing soil.

Flexibility: use appropriate materials
There was a major change in foundation design that occurred around the 1920s and 1930s when cement started being used in mainstream construction, and this was a shift from flexible foundations to rigid ones. It might seem strange to think that foundations and whole houses made of stone or brick could be flexible, but because of what the mortar is made of they definitely are! Lime and clay mortars have a very high degree of flexibility, whereas cement ones do not. We know that our old houses were and still are flexible, because they have changed shape over time. You can see in old houses around you that floors are no longer quite level and doors are no longer quite square, but in fact we seem to really like this and will pay more for houses that have these quaint features. Despite having moved as the ground has moved over long periods of time, these houses have not become unstable.

However, many houses built since the 1920s have experienced structural cracking, and have had to be repaired or demolished, as a direct result of using the rigid material cement as a mortar. Instead of working with the natural movement of the ground, we started trying to design houses that would somehow float on top of it, and this hasn't been very successful. Long expanses of wall laid with cement mortars need to have joints filled with a flexible material built into them to control cracking, which is why you see vertical joins every few metres in modern buildings, unlike in Victorian walls, which were able to run for miles around gardens and estates if necessary without any such joint because the lime mortar they were built with did this job itself. Modern houses are far less durable and won't last several hundred years as their predecessors did partly because of this lack of flexibility. This is not to mention the other undesirable effects to do with damp and condensation that are attributable to the use of cement in modern housing stock.

So it's really important to build flexibility into the design of your foundations, and you can do this by using flexible mortar made of either lime or clay.

Moisture control: use capillary breaks and vapour-permeable materials
All walls, whatever they're made of, whether brick-and-block or straw, will contain moisture because of normal human habitation – breathing, taking showers, etc. – plus foundations are in contact with the earth, which is often wet. So to keep the inside of our houses healthy and free from damp, we need to design a foundation and wall system that takes into account the ways moisture can get into the wall and provides pathways for it to escape naturally back out again.

If we make foundations of non-porous materials such as stone (though be careful, as not all stone is non-porous), engineering brick or recycled foamglass, then any moisture in the earth cannot travel upwards through them. There cannot be any rising damp, which is caused by capillary action wicking water through porous materials. And if we use vapour-permeable mortars such as lime or clay then any moisture that does find itself in there will migrate out through the mortar joints.

Traditionally, a capillary break was used to prevent the movement of moisture from the earth into the foundation. This is a layer of stones all the same size and at least 75mm (3") thick, such that water cannot pass up through them by capillary action, because the spaces between the stones are too great for this to happen. In many European countries this is still the preferred method of providing a damp-proof course, and it is becoming more popular again in the UK and Ireland as we are thinking through some of the causes of damp and trying to find sustainable solutions for them. Capillary breaks can be used instead of a plastic damp-proof course, particularly underneath solid floors.

Moisture in the walls will migrate downwards very, very slowly, because of gravity, so we don’t want a sheet of plastic catching this moisture and creating a problem in 20 or 30 years’ time. Instead, we want walls to sit on foundations that allow any moisture to travel down through them and evaporate harmlessly out through the mortar joints. One of the main problems with plastic damp-proof barriers is that they are waterproof! Instead we want a design with a capillary break and NOT a damp proof course that will let water pass down through it but won't let it travel upwards.

Thermal efficiency: use insulating materials

To meet the challenges of the twenty-first century – to build houses that are energy-efficient and require very little fuel to heat them – we have to make sure that the foundations do not allow cold into the house via what’s known as a ‘cold bridge’. The space we live in needs to be wrapped in a complete thermal envelope, with no gaps. So, while taking into account all of the above points, we also need to choose materials that will act as a heat/cold barrier, and use enough of them to actually work! Ideally these materials need to be non-porous, load-bearing and environmentally sustainable as well. The only real choice at the moment for the internal skin of a plinth foundation is recycled foamglas, and the infill between the outer and inner skin could be either a different type of recycled foamglass (rfg), or light expanded clay aggregate (leca). Insulating materials need to be sufficiently insulating to at least meet Building Regulations, but the Regulations in the UK and Ireland do not as yet go far enough to provide thermally efficient houses. The cavity-wall system will never provide a thermally efficient solution to house building and no amount of tinkering with it will alter this. However, if we did continue to use the cavity wall system, it would have to become very wide just to allow enough space to fit in the amount of insulation it would need to match the thermal efficiency of a strawbale wall.

Low-impact foundations

Clearly the most low-impact foundation you can possibly design is one that requires no intervention at all but simply uses the Earth itself. For all foundations the topsoil must be removed because this will always compress and compact, and if you have very deep topsoil this might mean that your foundation needs to be quite tall, to bring your building clear above ground level. But wherever you have good bearing soil, there is never any need to dig trenches into the subsoil. The most you may need to do is widen the width of your foundation as it touches it.

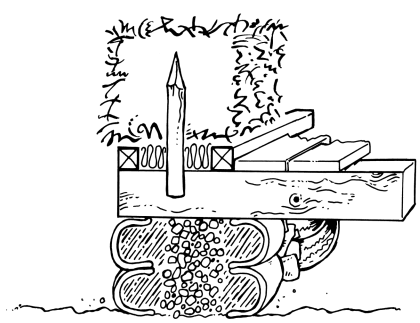
However, you may have some trouble arguing this with your building inspector, because these methods are not detailed in the Building Regulations Guidelines (mind you, neither are quite a few other common building methods). It's a common misconception that all houses need to have cement-filled trenches as their foundations.

Another low-impact solution is to use pillars or piers instead of a strip foundation. This disturbs the ground the least (hence 'low impact') and may cost less because of using less materials, but you must remember that the weight of the building has to be carried by something across the gaps between pillars. For a straw bale house this is usually done with a structural timber box beam, which has to be carefully designed so that it is strong enough to do the job we are asking it to do. Another consideration is that this means that the weight of the building is concentrated on several points rather than spread across a whole strip, so the ground below must be strong enough to take these point loads, which may be as much as 100kN/m^2 or more.

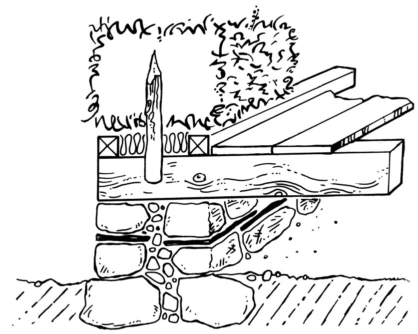
Foundations for good bearing soil

Here are some ideas for foundations on good bearing soil. Note no intrusive trenches.

Ram filled car tyres



Rubble filled stone plinth



Foundations for other types of soils

The following are options for different soil types, but they can be used on good bearing soil too.

Heavy clay soil

This is the only type of soil that is subject to frost heave, because clay absorbs water and so expands and contracts depending on water content and temperature. Most soils are NOT heavy clay, but nevertheless, most modern foundations are designed to prevent frost heave anyway – which adds a lot of unnecessary labour and expense!

- Any type of strip foundation: extend these to 600mm (26") deep into the clay. This ensures they are below the frost line and therefore can't be affected by frost heave. In some parts of the country this could be more or less, depending on the level of frost. Your building inspector will know your local conditions.
- Gabions: metal cages filled with stone or recycled brick and concrete. Extend these to 600mm for the same reasons as above.
- Car tyres: really only a version of gabions wrapped in rubber As above.
- Rammed stone piles: here a machine pile drives stone into the ground, many piles are placed for each building and then the tops of the piles are linked together with something solid. This can be done with low environmental impact by building stone plinths on top and linking the plinths together with a structural timber box beam, or with greater environmental impact by using concrete piles and a concrete bond beam. Rammed stone piles are a good solution for commercial buildings on heavy clay soils, as the action of ramming compacts the surrounding clay and makes it stronger.

Made-up ground

This describes soil that is of uncertain composition because it isn't just undisturbed subsoil. It may be a brownfield site – one where buildings have stood before. Or it may have been an allotment or landfill site.

- Self-compacting draining gravel, laid in a trench dug through the made-up ground to the subsoil beneath, with a limecrete cap on top to prevent outward spillage.
- Metal screws: similar to the rammed piles above except using giant steel screws made from mostly recycled steel.
- Gabions: the metal cages can be very useful to contain solid material for a foundation when the made-up ground itself might move.

All of the above solutions will need to be checked by an engineer, and the depth and frequency of them will depend on the weight of the building you are constructing and on what exactly is below ground.

Wet ground

This might be badly drained, or flood from time to time.

- Stone pile foundations with piers on top.
- Timber pile foundations raised above the ground.
- Raft foundations of timber, e.g. as in Winchester cathedral, which was built on a marsh.

Moving sand soils

As in wet ground, you need to use a deep foundation that carries you below the sand layer.

Sloping ground

Any type of pier foundation is suitable here, or stepped strip foundations.

Other considerations for foundations when using straw

Timber base plate

Strip foundations will always have a timber base plate on top, and pier foundations will have a structural box beam linking the piers. These provide fixing points inside and out for render stop, skirtings, tie-downs, etc., and also for short hazel stubs on which the first course of bales is imbaled(!), preventing it from sliding off the foundation. The base plate should also ensure that the straw itself is raised above the finished floor level by at least 25mm (1"), so that if you accidentally drop a bucket of water on the floor the flood won't touch the straw.

Tie-downs

The foundation design will often need to incorporate some method that allows for the wall plate and roof to be fastened down securely to it to prevent the roof from being lifted off by strong winds. If the roof is heavy (e.g. slate or planted) or the site is sheltered this may not be necessary.

Compression

It will usually also be necessary to fasten temporary compression straps to the foundations.

Fixings for door frames, etc.

Anything that fixes directly to the foundation, such as door frames, must have provision made for it. Structural box frames on buildings with solid foundations are usually bolted into the foundation or fixed to the timber base plate. Fixing posts for windows and doors are fastened securely into the base plate.

Foundation Design checklist

The above examples of foundation types have all been used successfully with straw bale buildings (and other types too) in the UK and Ireland. It is also possible to use these ideas in combination, as long as you follow these basic principles.

- Raise the bales off the ground by a minimum of 300mm (9") but preferably 450mm (18"), and by at least 25mm (1") higher than the finished floor level.
- Secure the bales to the foundations, usually with hazel stubs attached to a timber base plate.
- Protect the bales from moisture from above, below and outside by good design and choice of material.
- Make sure the foundations are as insulated as the straw walls above.
- Make provision for tie-down and compression straps if required.

Use local and natural materials as much as possible for the least environmental impact.