Understanding the "Bermuda" roof – leading to its effective repair

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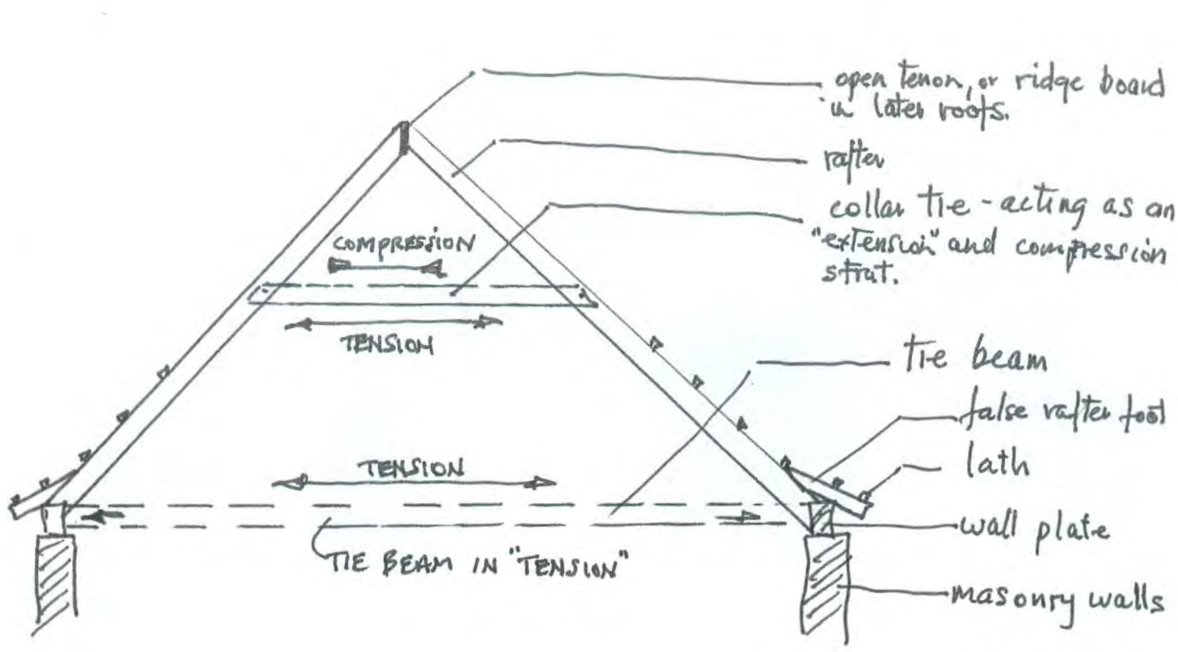
I have often heard compared the Bermuda cedar roof and the hulls of our stout early sailing vessels. Any comparison is superficial and helps little in "understanding" the structural elements and fastenings of the Bermuda roof.

The signal failure in a Bermuda roof is the deterioration of the wrought iron fastenings even though the high carbon content of these iron fastenings resists our corrosive salt air and prevents an even earlier collapse of the structural roof. A further problem occurs in the immediate site of the nail as it deteriorates and effectively "rots" the wood – further weakening the structure/strength of the wood.

To better understand the effect of the breakdown of the iron fastenings of the roof a few diagrams/drawings will help to see the "force vectors" acting on the various elements – including the walls. The walls have little or no capacity to resist outward (horizontal) forces of the roof and adding an "external buttress" to counter cracking or outward deflection of the walls is basically a "band-aid" solution of little value.



TYPICAL CROSS-SECTION THROUGH BOTH GABLED AND HIPPED ROOF

The collar tie acts both to stop the outward force on the masonry walls and, in compression, balancing the weight of the opposite sides of the roof against each other.

If both the collar ties and the tie beams fail, the outward force on the masonry walls is unopposed. The higher the "pitch" (i.e. the steeper the roof) the more of the weight of the roof is translated onto the masonry walls.

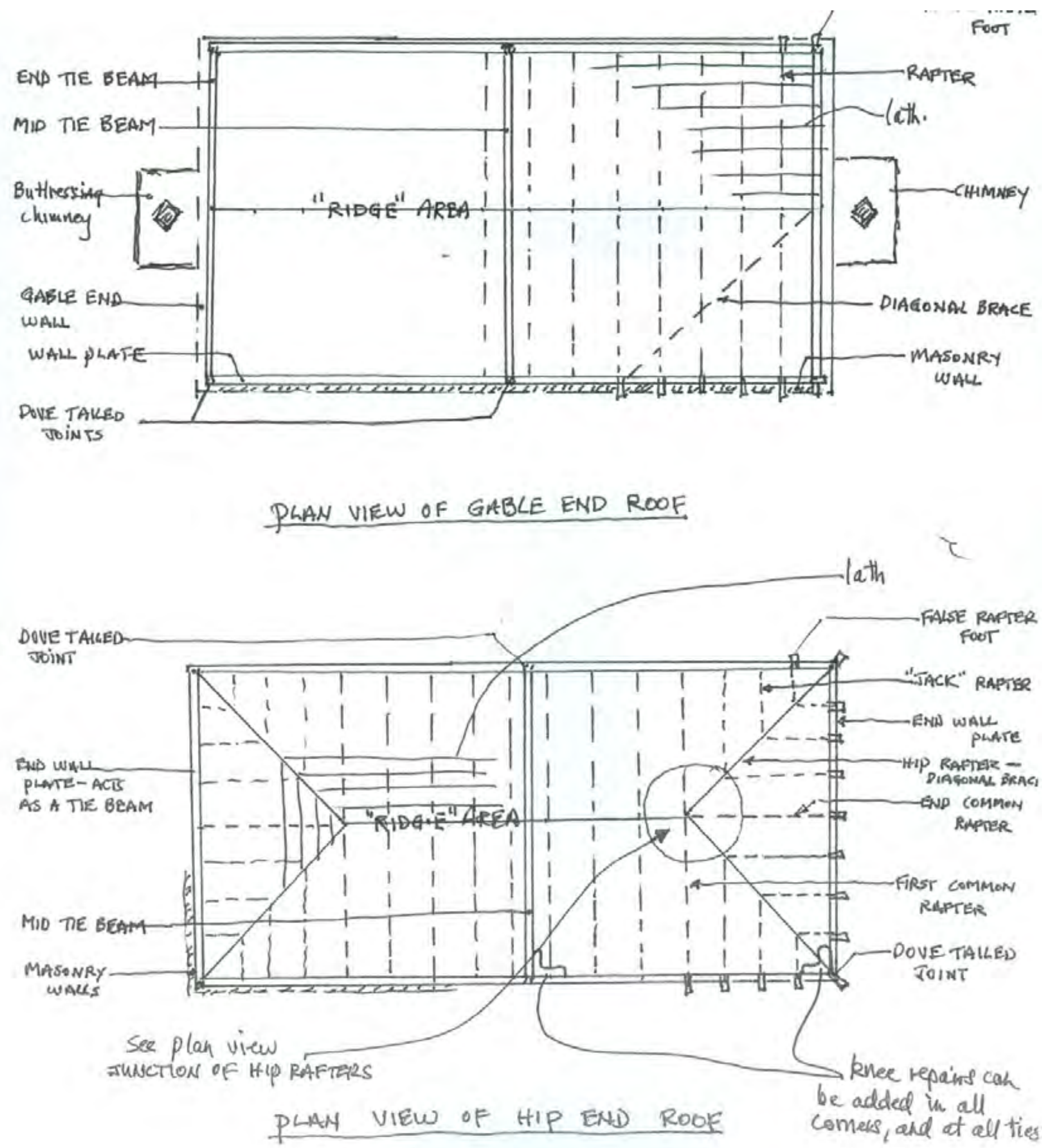
Gable v. Hip roofs

There are some critical differences between gabled and hipped roofs, but these are more in the structural form of the support timbers than in the general characteristics of the whole.

Gabled roofs have little or no support against movement along the line of the ridge. However, large "buttressing" chimneys at either end of most of the early buildings counter this lack of support. The placement of a diagonal support through the line of the rafters would counter this instability, but basically was never used – see diagram.

Hipped roofs are supported by the action of the hip end or ends acting as diagonals to brace the movement along the line of the ridge.

Further, once the slating is complete and the mortar hardened, the slate/mortar skin of both hip and gable roofs but perhaps more in the case of the gable, acts to stabilise the structure – much as a cone of any material has an inherent "strength" – so long as the underlying supports (the rafters and lath) are intact.



See detail of circled hip area on page XXX.

Gable roofs

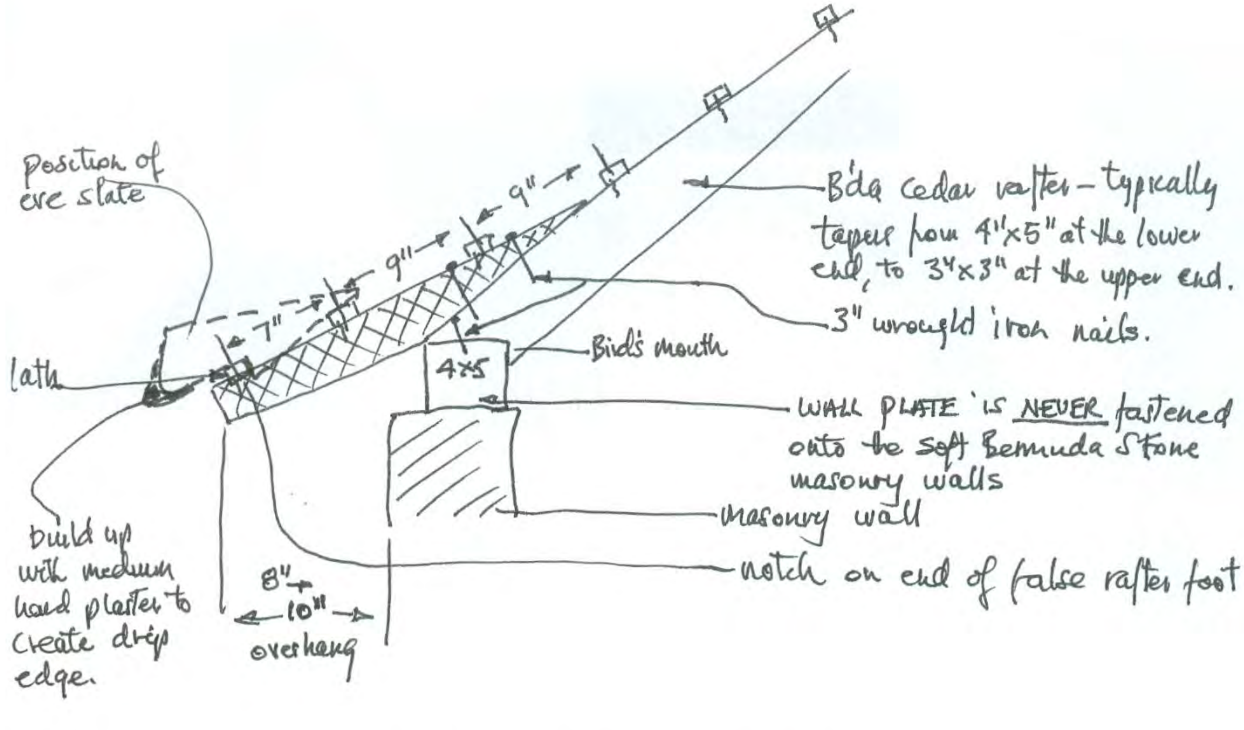
A gable roof is possibly "stronger" than a hip roof when the fastenings substantially deteriorate, mainly in that it is a simpler structure. In the case of the earlier gabled roofs the chimneys act as “buttresses” and support the roof from moving sideways. Each pair of rafters is tied to the next by the laths - only the laths – and only until the nails rust/deteriorate. Once these ties between rafters break down, the roof is still relatively stable laterally because of the buttressing chimneys. BUT the laths also perform another function – and that is “anchoring” the slate. Each slate sits on its appropriate lath when first laid and is usually “stuck down” only by its own weight although very occasionally the slates have a notch which sits on the lath and “hooks” or holds the slate in position. When the nail holding the lath onto its appropriate rafter rusts away there is nothing but the “friction” of the slate on the lath, and, in turn, the lath on the rafter to hold the roof from slipping. Early Bermudian houses inevitably have a “steep” pitch – usually minimally a 10/12 pitch which is approximately 42°. Many of the earlier houses have a 12/12 or “half” pitch (half of 90 degrees) which is 45°. This lessens the horizontal force vector and thus lessens the outward thrust on the walls. This outward thrust is countered only by the action of the collar ties and the tie beams.

As can be seen from the cross section diagram on page XXX (probably 1), the collar tie acts to “tie” the opposing rafters together – from pushing the wall plate (and walls) outward - and simultaneously as a compression strut to counter the inward bending movement of the rafter. The downward force of the structural beams and the weight of the slate and mortar (and often 300 years of accumulated lime wash) further act to counter lift, but also increase the load on the wooden support system. The tie beams at wall plate level (i.e. the level of the top of the walls) act in “tension” to stop the weight of the roof from pushing out the walls. These tie beams are fixed into the wall plate with a “dovetail” joint – cut into the wall plate. The iron fastening here is usually minimal – a 3" skewed nail – thus relying mainly on the natural friction of the joint. When this dovetail joint deteriorates, the best treatment is to “tie” the tie beam and the wall plate with a right angle bracket – a knee. Hence it should be assumed that a “knee” is often/usually a repair element.

Rafter feet and false rafter feet

Another “feature” of a Bermuda roof which helps to stop slates slipping is the false rafter foot. It is an applied element mainly affording an opportunity for the roof to “overhang” the walls. This overhang protects the walls and wall plate but it also tips up the bottom edge of the roof slightly.

The final element to counter the “slide” of the roof is the first lath’s fastening onto the false rafter foot. There is usually evidence that this first (or lowest) lath was fastened with a 2½" nail into a “notch” cut in the false rafter foot (see diagram HOPEFULLY BELOW OR OPPOSITE)."



FALSE RAFTER FOOT – DETAIL

NOTE: THE DRAWING ABOVE DOES NOT SEEM TO SHOW ANY REPAIRS SO I HAVE PUT IT HERE BEFORE THE REPAIR SECTION STARTS. BUT THERE IS ANOTHER DRAWING WHICH I HAVE TEMPORARILY PUT AT THE END OF THIS PAPER WHICH IS SUBSTANTIALLY THE SAME. IF I COULD FIND SOMEWHERE ELSE TO PUT THIS ONE THEN THE ONE AT THE END COULD COME HERE.

REPAIR OF A BERMUDA ROOF

The invariable reason for the ridge opening in a Bermuda roof is most or all of the failures mentioned above. The standard treatment for this "sliding" is to drill holes through the slate roof immediately above the rafters and to drive into the rafters wooden pegs or "nails". These are called "tree nails" or "trunels". The peg can be driven into the rafter through a fairly small hole in the slate and left "proud" or cut off flush and a daub of lime mortar placed over the end to waterproof the penetration. This treatment can be very effective and two trunels per rafter can be sufficient to arrest the roof's slate from sliding. BUT this should actually be considered a temporary repair only. Refastening the lath, which is usually done from within the roof, AND repairing/refastening the false rafter feet is a "permanent" repair.

Another method of external pinning of a roof is to let in a ⅜" x 5" stainless lag bolt through a 1½" hole in the slate, above and into a rafter and then apply a masonry plug. This is certainly easier and stronger and more durable that the wooden trunels.

Repair of a false rafter foot

It is not unusual to find repaired/replaced false rafter feet on older houses. The false rafter foot is usually applied to the foot of the rafter with two 3" iron nails. These deteriorate and can be repaired by drilling an approximately 2" hole through the slate above this joint and refastening with a 5" to 8" stainless steel lag bolt.

When effecting a repair/replacement of rafter feet, usually the first lath has also substantially/completely deteriorated. At this point of repair, a notched false rafter foot can be fastened and, simultaneously a new bottom lath added to fit into the notch that was originally cut in the eave slate – see diagram. This strategy further acts to stop the slate roof "sliding" down.

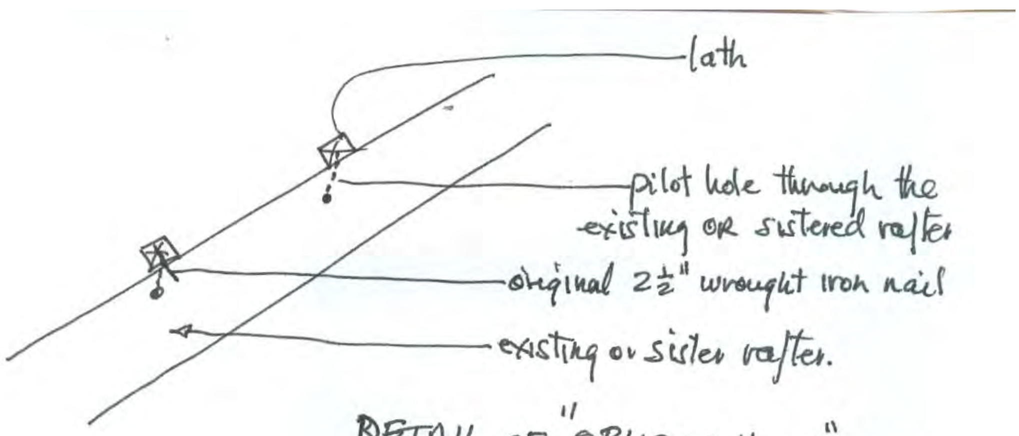
Repair/refastening the lath

From the outside

When the plastered ceilings are intact it is possible to drill a series of small holes, perhaps 1½" in diameter, through the slate above each lath's position on the rafter and nail down through the roof slate. Inevitably the iron nail will have "blown" a fairly large hole in the lath, but a pilot hole can be drilled through the sound part of the lath into the underlying rafter and then a stainless pin or square headed screw may be fixed. The repair of the multiple holes might seem daunting, but by using a mix of approximately 5 parts sand, 1 part lime and 1 part cement AND thoroughly soaking the sides of the holes with a fine spray from a garden hose and nozzle before filling, dozens of holes can be filled in a short time. Many traditionalists recommend a far weaker mortar mix but the author has used this nominally stronger cement to sand ratio very satisfactorily as long as he uses at least an equal part of lime to cement. Lime mortar, in fact, shrinks and cracks more than cement and sand mortar.

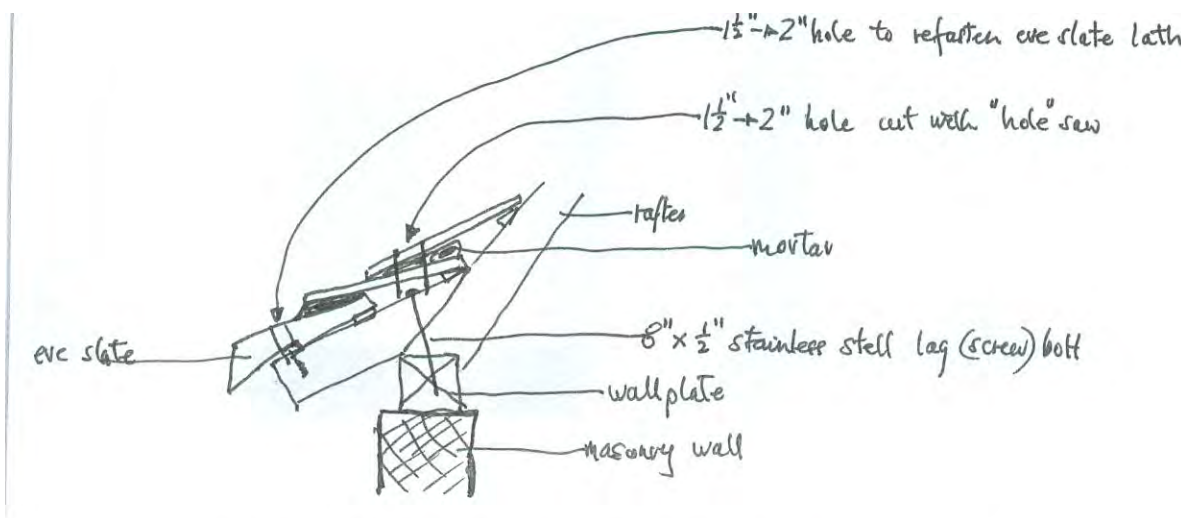
Fastening lath from inside the roof

The alternate fastening method of tying lath to rafter is to drill a hole – a pilot hole – through the side of the rafter below the lath, usually to only catch the bottom one quarter inch of the lath, and to drive a stainless nail or screw to mainly act as a "stop" to prevent the lath sliding down the rafter. It is not so important to "fasten" the lath onto the rafter as to stop it sliding. Obviously the lath can be better fastened by drilling holes in the slate and working from above. Thus, if the ceilings are down, the job can be done more effectively from inside using the "oblique nail" technique – see diagram below.



DETAIL OF "OBLIQUE HOLE" as a pilot hole for the stainless steel fastening screw.

The term "oblique nail" is used to describe a nail that passes through part of the solid rafter and enters into a part of the lath where there is solid, non-deteriorated material. A "pilot hole" is drilled with an ⅛" steel bit entering the rafter from 2" below but in a mostly vertical direction (as opposed to perpendicular to the lath) and into the lower middle of the lath. The drill bit has to exit the rafter under the lath at approximately 1" from the outer edge of the rafter. This pilot hole should clear through the cedar rafter but not enter the lath. The oblique nail or screw then is fastened through the pilot hole to force itself into the lath and anchor the lath to the rafter. If the lath is substantially deteriorated the nail will still act as a friction "stop", to stop the lath sliding down the rafter. As mentioned, the weight of the slate roof "holds" the roof down against high wind lift, but it does not stop the roof from sliding if the lath can slide.



Fastening of False Rafter foot to Wall Plate

The original fastenings can be seen diagrammatically above. A new lath can be fastened in place through the 1½" hole shown toward the lower end of the eave slate. Deterioration can usually be repaired with stainless steel screws and strong cement and sand used to fill the rotten rafter ends. If the rafter feet are too rotten, new ones can be "forced" into place after the old ones are “smashed” out. They should be replaced one, or at most two, at a time, so as not to leave the masonry eave overhang unsupported. The deteriorated rafter feet will usually split with a 1½" chisel and often the nails are almost non-existent. The new appropriately angled and “lengthed” (i.e. measured) false rafter foot can be driven into place with light blows from a ten pound hand mallet. Once in place a deep pilot hole can be drilled through the hole in the slate, through the false rafter foot, through the end of the rafter and into the wall plate. The optimal position of this hole is to centre it on the width of the wall plate and angle the hole off the vertical to catch/pick up the best centre on the three elements – the false rafter foot, the rafter and the wall plate. The repair above reties these end elements together and will by itself substantially retie/refasten a roof.

<u>Tie beams</u>

As mentioned earlier, the “tie beam” is a connection at the top of the wall – tying the opposite wall plates together. Deterioration in these ties and deterioration in the corners of rooms can be countered with knees that are fastened through both elements (the tie beam and wall plate) with 8" – 10" steel lag bolts of either ⅜" or ½" size. It is better to use a length of stainless steel “endless threaded bolt” as the fastener if access can be gained to tighten up the nut that will be “behind” the wall plate. An alternate but less “aesthetic” tie is a stainless steel angle iron of ¼" x 3" bent at least 16" long on both ends.

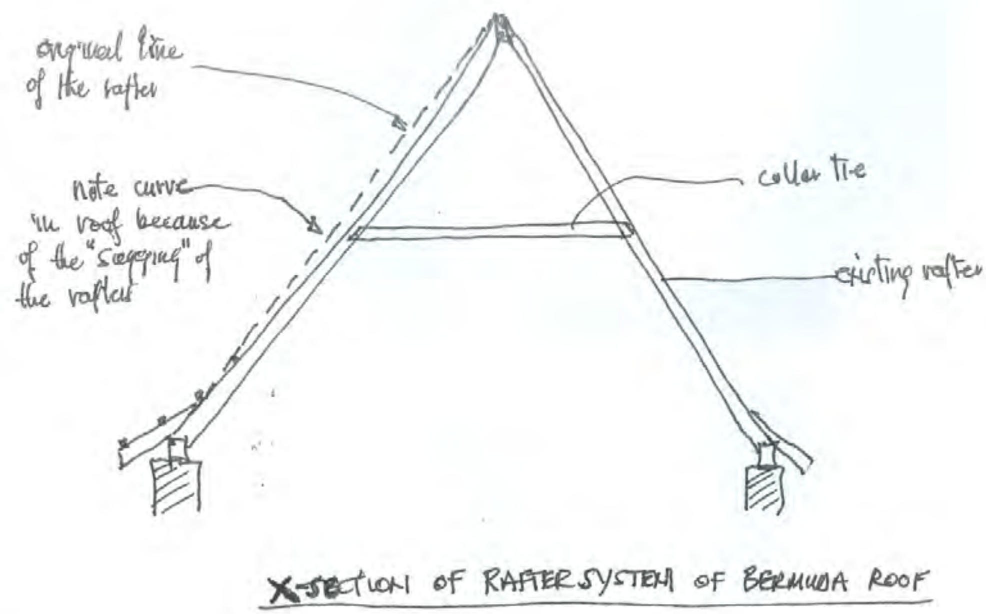
<u>Collar ties</u>

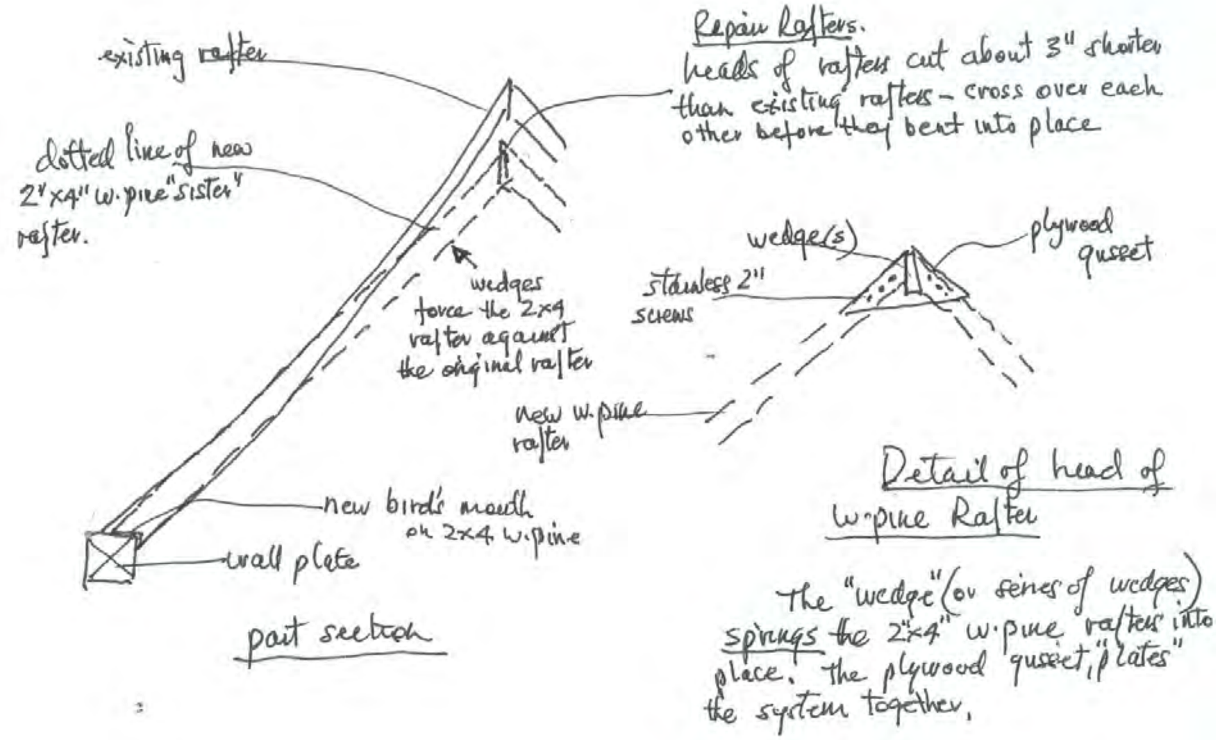
Commonly, there is deterioration of the collar ties – almost always the fastening nails are rusted and doing little. It is not uncommon for there to be a shallow dovetail joint fastening the collar tie to the rafter. Often the collar ties, which were usually adzed straight on the lower side only, are very light and can be replaced with a wolmanized (treated) pine element if appropriate cedar collar ties are not available. This depends on the “aesthetics” if there is an exposed ceiling. Collar ties need to be carefully refastened with either a ⅜" lag bolt or a ⅜" endless bolt but an effective fastening can be achieved with two ⅛" x 4" stainless screws driven into “pilot holes”. Stainless screws are available locally with a square or Robertson head. The usual “blow out” deterioration of the 3" wrought iron nail has to be considered – sometimes it is best to hold the collar tie in place with a large enough “G” clamp, after using a light ⅛" x 4" gauge stainless screw as a partial fastener, and then to drill preferably through the deteriorated iron nail, or immediately alongside the nail, for the new fastener pilot hole.

<u>Rafter repair</u>

Another common problem is that a rafter cracks or breaks, particularly where the rusting collar tie fastener has weakened the rafter. A 2" x 4" piece of wolmanized pine can be fastened to extend beyond this break a minimum of 30" above and below the crack. But a longer length is better. This support piece can be adequately fastened with three to four ⅛" by 4" stainless steel screws above and below the break.

In some cases it is necessary to “sister” in complete new rafters or rafter pairs (a “pair” are two rafters that meet at the ridge). This can be done very effectively using two lengths of 2" x 4" treated pine with the appropriate bird’s mouth on the lower ends BUT cut about 2" to 3" shorter than the original rafter (see drawings on next ???? page).



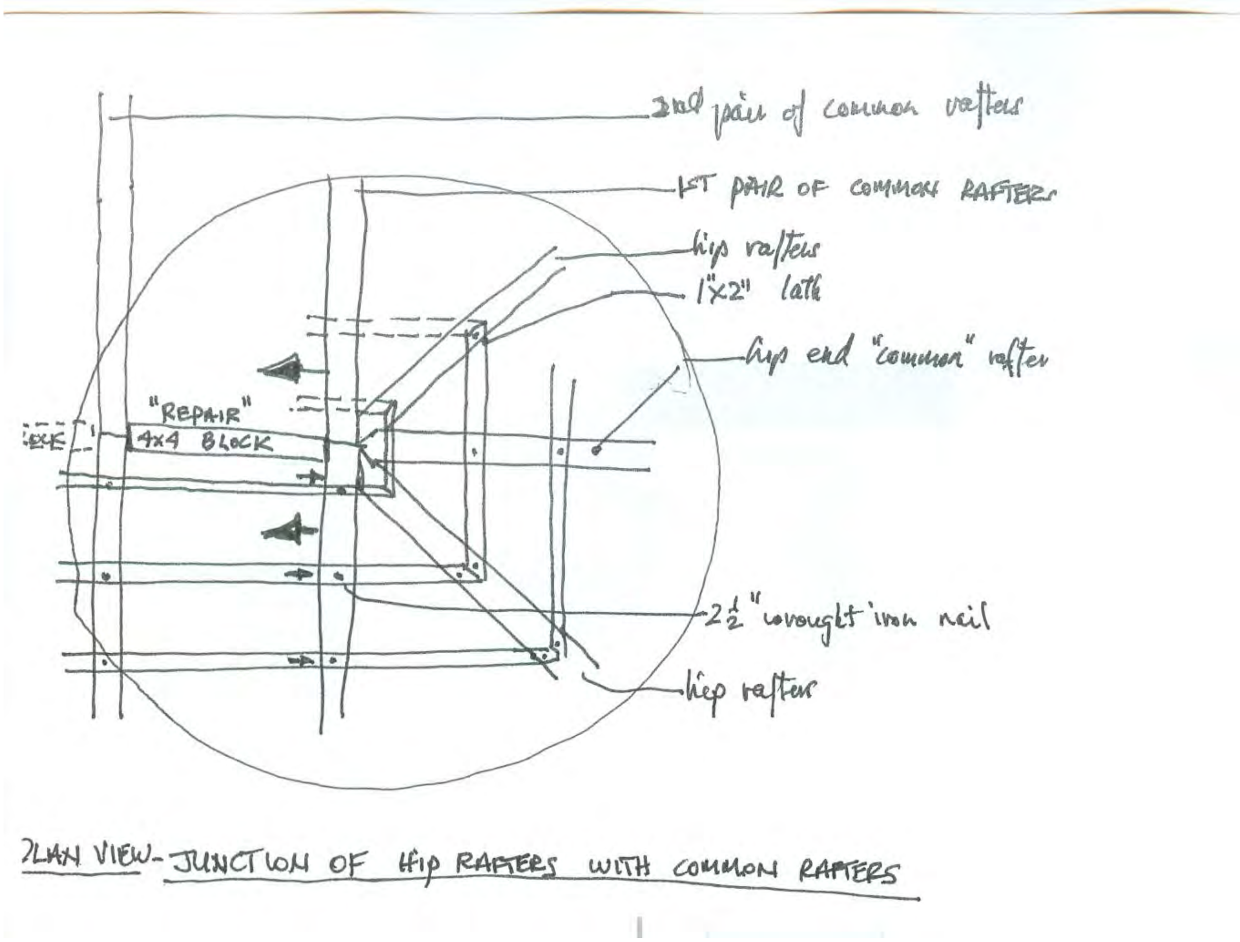


The 2" x 4" wolmanised pine "sister" rafters can be put in place beside the deteriorated rafters and then bent to approximate the curve of the settled roof by sequentially driving in more "wedges". Often two thinner wedges (2" tapering to 1½" for instance) can be replaced with a final 4" tapering to 3½" wedge. The heads of the two rafters, with the wedges in place, are then "locked" in place with a ½" treated plywood gusset/plate, then finally oblique pilot holes can be drilled through this new rafter to fasten into the existing laths to tie these laths from slipping. Often the force of "springing" the sister rafters into place will substantially crack the slate above.

These cracks can be repaired with the usual "soaking" with water and the normal roof repair mortar mix. It is surprising how effectively the repair of the sagging rafters will permanently repair the roof.

Hip roof repairs

Everything that applies to the gable roof system basically applies to a "hip" roof – that is, the lath fastenings can deteriorate, the false rafter feet can deteriorate, the collar ties can break down. BUT the critical difference is that, although when newly fastened the "hip" ends buttress or support the sides, when the lath fastening deteriorates there is nothing acting as a compression strut along the line of the ridge and the whole weight of the hip ends will inevitably deflect the first pair of common rafters on both ends of the main "pitch" of the roof so that the basic hip wooden support structure falls and no longer supports the hip end slates.



Detail of hip roof plan on page XXX

When the 2½" wrought iron nails deteriorate and completely break down there is nothing to oppose the weight of the two hip rafters and the hip end "common" rafter. This weight/force acts in the direction of the two large arrows shown above. The action of the lath when held in place is shown by the small arrows. The laths act collectively as an effective system of struts in compression – these act to counter the weight of the hip end and timber supports.

The 4" x 4" repair block between the 1st and 2nd pairs of common rafters acts as a "compression strut". This block in turn acts on the next repair block along the ridge until finally the weight of the timber support structure at the opposite hip counters the weight of the "other" hip. This series of repair blocks is an effective "ridge board".

There is a simple treatment for this problem and that is to put a series of, say, 4" x 4" blocks or “noggins” between the heads of the rafter pairs – from one end of the ridge to the other between all the adjacent rafter pairs. These noggins can be cut perhaps one sixteenth to ⅛" over length and forced between the adjacent rafter pair heads BUT a tight “friction fit” only is best. Of course, this is effectively what a ridge board does in the hip roof of a modern house. Ridge boards were not used in Bermuda roofs until almost certainly the 1830s. About this time pit sawn or circular sawn pine/fir became available from North America and had effectively replaced cedar rafters by 1850. After 1850, instead of an “open tenon” or “mortice” to join rafter pairs in the mid line, a mitred cut reposing against a ridge board (usually only of a 1" x 6" dimension) replaced the open tenon/mortice joint. The ridge board acted as a “compression strut”. This “compression strut” addition (i.e. the insertion of the noggins) is needed to effect a stabilising repair to an early hip roof.

The “jack rafters” (that affix to the common “hip rafters” with the usual 3" wrought iron nails) also need to be fastened with either a stainless steel 5" x ⅜" lag bolt or a pair of 4" x ⅛" stainless screws appropriately positioned.

When drilling hole systems for any of these fastenings, it is critical to slightly overbore the hole through the piece of wood that is being fastened to the receiving or main element. For example, the collar tie should have a large enough hole to allow the lag or carriage bolt to pull the collar tie up firmly to the rafter. This is an important basic principle of fastening and prevents the screw in the piece being fastened from binding and stopping its being pulled tight.

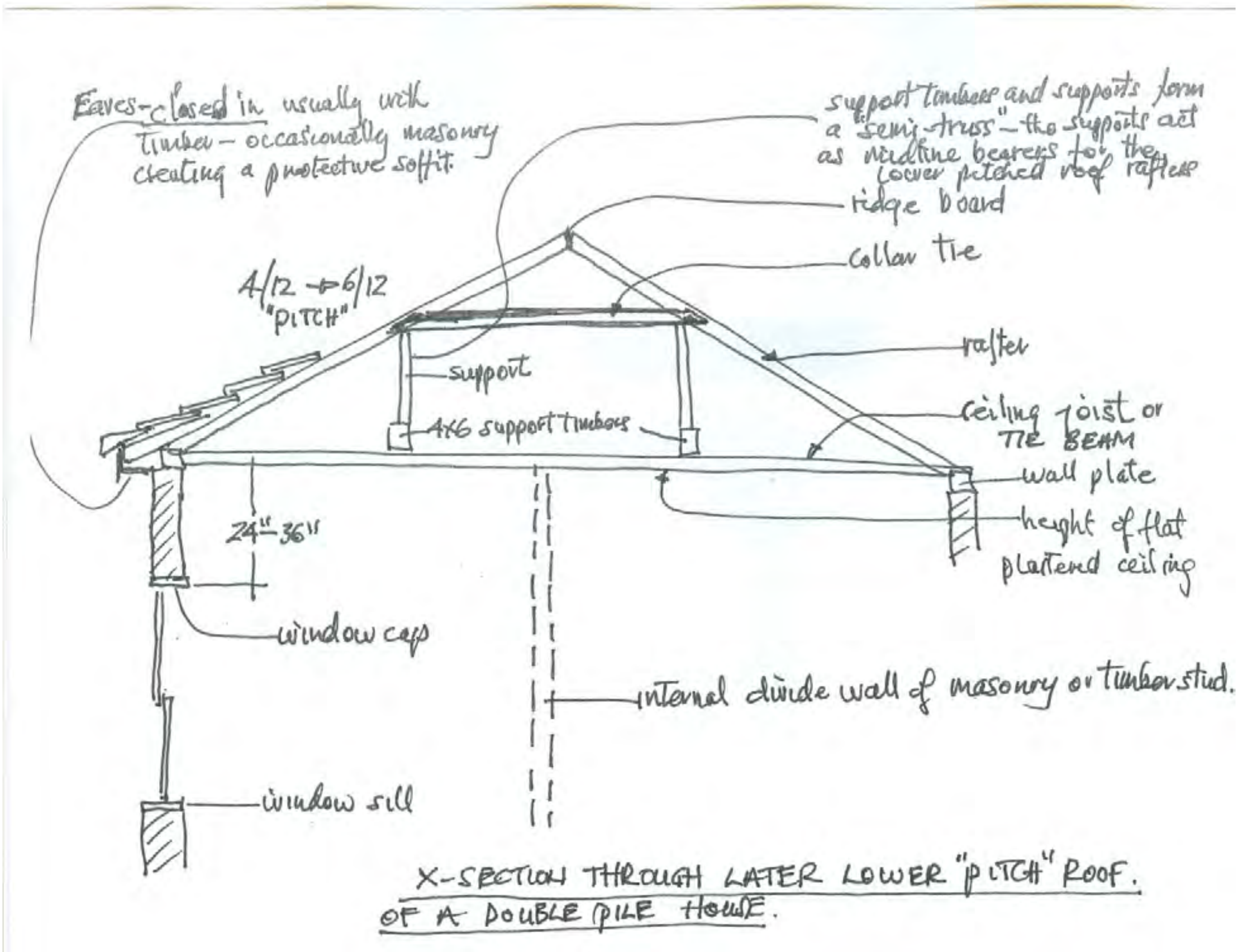
By the early 19th century when hip roofs had largely replaced gable ended roofs, there was much less need for the end buttressing of a chimney. There was also a movement to “double pile” houses (houses that were two rooms wide instead of the “cottage style” of only one room wide or “single pile”). These changes meant that there was also an attendant lowering of the pitch of the roof from a 10/12 to a 6/12 pitch or even less. The effect of this lower pitch and wider roof span was to put more horizontal force on the walls. Collar ties were lowered and there had to be structural ceiling joists (effectively tie beams at ceiling or wall plate level which acted to tie the opposite wall plates together). Of course, with these flat ceilings (replacing the trayed or vaulted ceilings) the window caps were still at a traditional 6'8" to 6'10", but there were three to five masonry courses above these window caps – effectively raising the wall plates. Some of the houses built in this transitional period, between, say, 1800 and 1850, need or will need restorative work to their roof structures – particularly the compression strut replacement of the “non ridge board”. And occasionally a set of new collar ties at a lower level than the original ones to create a tension tie from one wall plate to the other will be needed. This repair can often be done in the attic space even if ceilings are in place.

Another weakness of a hip structure, especially on the larger double pile houses (where the hip end is over 20' and often up to 30') is that there is no cross tie beam from one hip end to the other. There are cross ties across the shorter span of these houses – the tie beams or ceiling joists mentioned above. These larger houses seldom have buttressing chimneys and are therefore at risk for the end walls to “bulge”. As the walls are pushed out new forces appear on the fastenings and stresses can often compound. When the White House on Salt Cay in the Turks and Caicos Islands was repaired, a tie was created from one central “common” hip end rafter, across the length of the house, using half overlapped and fastened 2" x 4"s, to the other “common” rafter. That basic house is 100 feet long and 50 feet wide and, although the wall plate was 12" x 12" fir, the bending moment on the hip ends at the other end of the house was unopposed and incredible. This is an unusually large width but is an extreme of the problems with these mid 1800s hip-ended low pitch houses found in Bermuda. Because the wall plates are raised and the ceilings are flat, access to effect repairs is simple (working in the attic void).

On hip roofs there is often this larger space above the ceiling joists, a true "attic" space which is easier to access and to effect repairs – for instance the "oblique" nails to "catch" the laths may be fastened with this easier access. In the case of these lower pitched roofs there is, of course, a much smaller sliding moment because the roof pitch is perhaps only 30° and the gravitational "sliding vector" is considerably lower than in the earlier higher pitched roofs. In this sense, there will be fewer problems with these hipped roofs so long as the collar ties and/or ceiling ties are intact/fastened.

Further rafter feet treatment becomes less critical because there is a smaller vertical stress or sliding moment and the eave slate is not as critically held in place by the first lath on the false rafter foot. And generally with an enclosed eave or soffit space under the eave slate overhang there is less deterioration; in fact, often there are no false rafter feet – the rafter's "foot" overhangs the wall plate. The enclosed eave became common by the mid 1800s.

<u>Semi-truss roofs</u>



Occasionally mid 1800s and later houses with a lower pitch roof are built with a "semi-truss" system. This is a support system to bear some of the weight of the considerably longer rafters needed to span the double pile house. The ceiling joists are usually at 24" on centre and are often tied at every 6th joist with a cedar knee. This special tied joist is thus really a tie beam – tying the adjacent wall plates together. In that the roof pitch is much lower than the earlier single pile house and the rafters are longer because of the wider roof span, the lateral force vector is enormous (compared with the earlier narrower roofs) and the knee construction, which supports the usual dove-tailed joint, is critical.

Repair and replacement of lath

When laths deteriorate or drop below their position of support for the slate, or when the fasteners have substantially “rotted” the laths, or in the extreme case where the slate has slipped off its rest on the lath and the lath has stayed in its original position, the laths themselves need to be repaired and/or repositioned.

New lath can be “fed” in through slots cut in the slate in hip roof systems, and knocked up under the slate just below the original laths and fastened with the usual oblique holes drilled through the rafters and then fastened with stainless steel screws or nails. Slots can also be cut in the vertical gable end stone and lath fed in and knocked into position under the slate and fastened. The repair of these “slots” is done with the usual lime mortar mix.

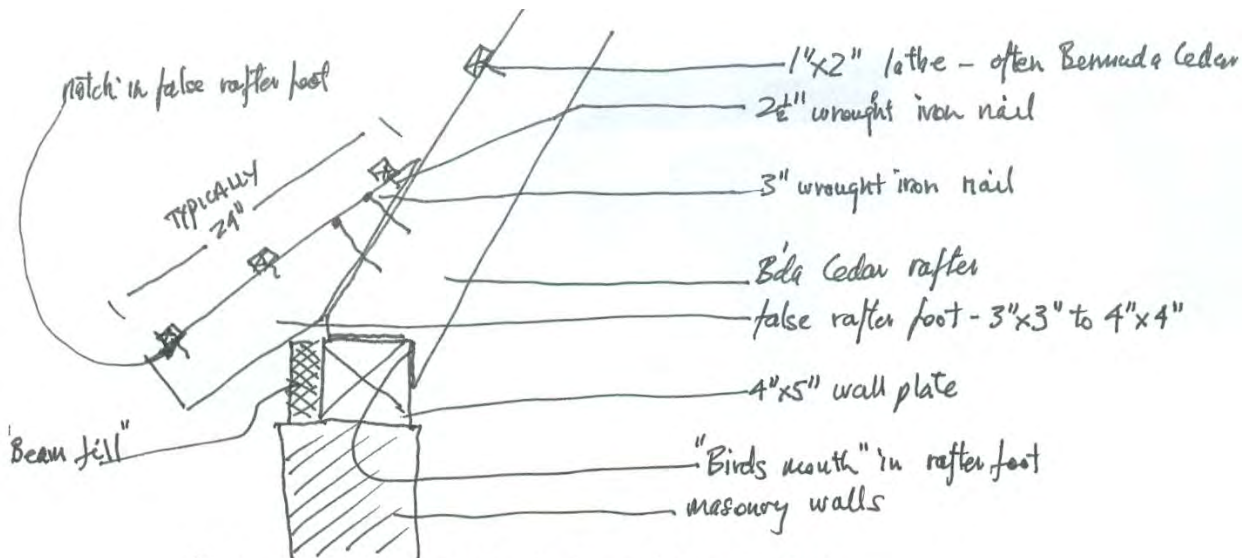
Conclusion

In summary, the biggest problem with Bermuda slate roofs (and this applies to both “flat” and “lapped” slate roofs) is the deterioration of the fasteners. Some fasteners are more critical than others – as explained, depending primarily on the roof pitch. Once the roof cracks, and especially if the ridge opens, masonry patching is only a “stop-gap”, not a repair. If the roof cracks there is something happening with the roof structure that needs dealing with, but often not as a matter of extreme urgency. Bermuda slate roofs are surprisingly “forgiving”. But cracks allow moisture in through the very porous Bermuda stone slate and the lath, the basic supports of the immediate load, start to rot.

Bermuda stone roofs are “tolerant” of considerable masonry repairs. For instance, holes through the slate for “top” fastening as well as larger slots for new lath do not cause problems so long as the mortar is relatively weak and the roof to be patched is literally soaked – it cannot be too wet! As the mortar dries, and it does so very quickly, the repair can be lightly “sponged” off to smooth and then coated with a white cement wash within an hour of mortar application. So do not fear “chopping into” a roof. Using a small cutting wheel electric grinder is better than “hacking” with a hatchet because the impact from a hatchet does too much damage to the weakened structure.

February 2008

I can't work out where to put the drawing below. It doesn't seem to fit with any of the repairs and is substantially the same as the one coming under Rafter feet and false rafter feet except that it doesn't have slate. But it does have a bit of other information which I quite like.



Detail of False Rafter foot and Wall plate