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Designing RETAINING WALLS, BULKHEADS AND SEAWALLS OF TREATED TIMBER

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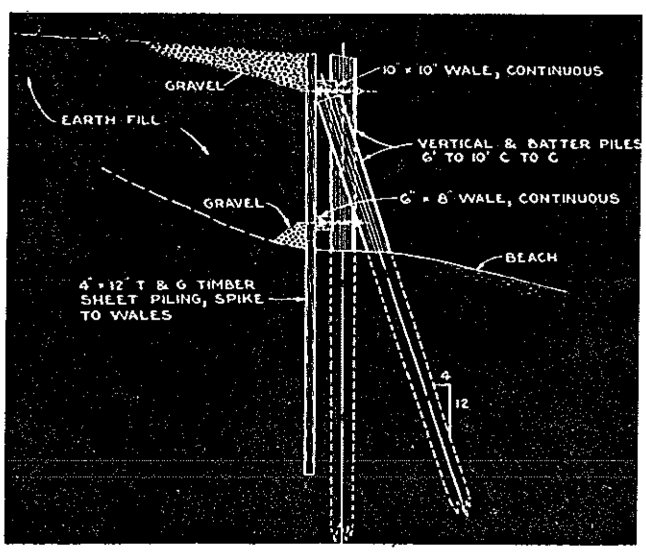
Decades of Service Prove The Efficiency of

TREATED TIMBER RETAINING WALLS, BULKHEADS AND SEAWALLS

Part I of Two Part Series

THE GENERAL efficiency and low cost of well-designed and well-built treated timber bulkheads, retaining walls and seawalls have long been recognized by engineering officers in charge of construction and maintenance departments of the Bureau of Yards & Docks, railways, national and state highways and many other public and private engineering organizations. The dependability of these timbered earth retaining structures has been proved through many decades of successful service. The most dramatic evidence of this efficiency has been demonstrated repeatedly by bulkheads along the Atlantic coast. These have protected shore properties successfully from repeated assaults of hurricanes and severe storms for 50 years and more.

The Navy's Bureau of Yards & Docks has found pressure-treated timber to be particularly effective in seawalls and bulkheads used to protect shore properties and to prevent beach erosion. This design is used extensively in the Chesapeake Bay area and represents the type built near the Patuxent, Md. Naval Air Station.



Such structures have been equally effective in many other areas. For instance, back in 1935-36, the Weyerhaeuser Company built a heavy duty seawall and some 4,300 lin. ft. of heavy duty bulkheads with pressure-creosoted timber in the tidal zone of Puget Sound to protect their operations at two mill sites near Everett, Washington. A detailed inspection by a competent engineer 28 years later revealed that these structures were still in prime condition and good for many additional years of service despite their exposure to scores of severe storms and marine borers which infested the saline waters of the Sound. About the only maintenance involved, during the last 30 years, according to superintendents of the two mills, was the periodic reapplication of bitumastic coatings to the exposed steel fastenings and recoating of the tops of the timber piles.

Heavy Duty Design Assures Durability

The relatively simple designs of these structures, as illustrated in the accompanying drawings, were developed to provide long-time durability in retaining hydraulic fill and to protect three sides of the sulphite

Embankment of pressure creosoted timber bulkheading at Patuxent River Naval Air Station, Md. extends 9100 lin. ft. along most vulnerable sections of 16,000 lin. ft. total beach front.

Decades of Service Prove The Efficiency of

TREATED TIMBER RETAINING WALLS, BULKHEADS AND SEAWALLS

Part 2 of Two Part Series

THE most common type of timber bulkhead is the conventional sheet-pile wall held in line by guide piles and heavy timber wales. Retaining walls with horizontal planking supported by round timber piles or posts also are quite common. Spacing of the posts depends on the thrust of the backfill and on the thickness of the horizontal planks, which are continuous beams on several supports and loaded uniformly over their lengths by pressures of the backfill at their respective levels.

For heights of 7 ft. and less the support posts, if set to recommended depths, provide ample resistance to overturning, tilting or replacement without tiebacks or other lateral bracing in any but the poorest soils. Higher walls are tied back to deadmen or anchor piles by rods or cables fitted usually with turnbuckles for easy adjustment. Such walls are sometimes braced by batter piles.

Horizontal Thrust

The force which acts on the usual sheet-pile bulkhead or timber retaining wall is the horizontal thrust exerted by the restrained earth mass composing the backfill, and its intensity increases directly with depth. To be stable and to remain in satisfactory alignment, the wall assembly must be proportioned to withstand this lateral pressure without exceeding reasonable working stresses for the several timber members or the soil.

An exact determination of lateral pressures which a confined mass of earth of moderate height can exert is impractical from the soil information available on the ordinary project. Elaborate computations generally are not warranted for walls less than 20 ft. in height, and for these heights such computations can be justified only after careful analyses of the mechanical properties of the backfill soils. To justify them too, the backfill must be placed in exact conformity with conditions assumed in the design calculations. Lateral earth pressure from restrained earth masses has been found to vary as much as 30 percent, either side of the average, during a year's time, because of the effect of seasonal changes on soil properties.

The pressure increases directly with the depth as shown in Fig. 1.

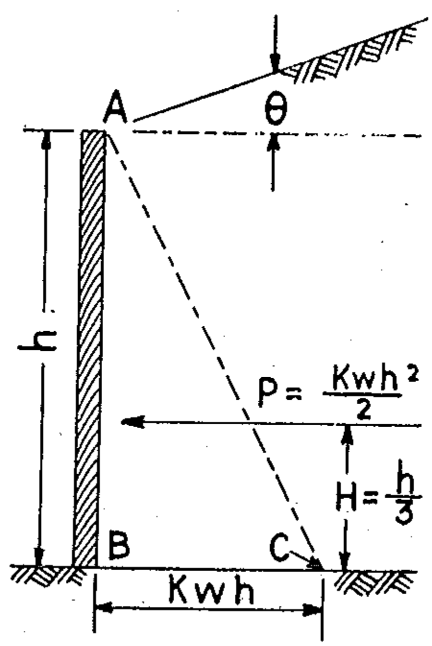


FIGURE 1

The Rankine formula is commonly used for estimating lateral pressures exerted by an earth embankment on a restraining bulkhead or wall.

For computing the horizontal component of pressure the formula can be written.

$$P = \frac{Kwh^2}{2} \quad \dots\dots\dots\dots\dots \; 1$$

Where: P = total earth pressure on wall in lb.

w = weight per cu. ft. of earth in lb.

h = height of wall in ft.

$$\text{and } K = \text{Cos}\,\theta \frac{\text{Cos}\,\theta - \sqrt{\text{Cos}^2\theta - \text{Cos}^2\Phi}}{\text{Cos}\,\theta + \sqrt{\text{Cos}^2\theta - \text{Cos}^2\Phi}}$$

Where: θ = Angle of slope with horizontal

Φ = Angle of repose of earth in backfill

When the surface of the back slope is horizontal, θ is zero and the formula for K reduces to:

$$\frac{1 - \text{Sin}\,\Phi}{1 + \text{Sin}\,\Phi} \quad \dots\dots\dots\dots\dots\dots \; 2$$

The Manual of the American Railway Engineering Association recommends investigation and classification of the backfill with reference to the following soil types:

1. Coarse-grained soil without admixture of fine soil particles, very free-draining (clean sand, gravel or broken stone)
2. Coarse-grained soil of low permeability due to admixture of particles of silt size
3. Fine silty sand; granular materials with conspicuous clay content; or residual soil with stones
4. Soft or very soft clay; organic silt; or soft silty clay

5. Medium or stiff clay that may be placed in such a way that a negligible amount of water will enter the spaces between the chunks during floods or heavy rains

Where soil tests are impracticable, the following properties of the backfill soil, viz.: unit weight and angle of internal friction (angle of repose) may be taken from the following table:

Soil type	Unit Weight Lb. per cu. ft.	Angle of Internal Friction
1	105	33° 42′
2	110	30°
3	125	28°
4	100	0
5	120	0

For example, assume the following numerical values for the dimensions and quantities indicated on Fig. 1: $w = 100$ lb. per cu. ft.; $h = 12$ ft.; $\theta = 20°$ and $\Phi = \tan^{-1} 2/3$ or a slope of 1½ to 1; $\cos\theta = 0.94$ and $\cos^2\theta = 0.884$; $\cos^2\Phi = 0.692$ and $\sqrt{0.884 - 0.692} = 0.438$

Then:

$$P = \frac{100 \times 144}{2} \cdot 0.94 \cdot \frac{0.94 - 0.438}{0.94 + 0.438} = 2460 \text{ lb.}$$

which is the area of the triangle ABC, Fig. 1, for the assumed quantities. This force acts at ⅓ the height of the wall or at 4 ft. above the base.

Because of the impracticality of appraising accurately the soil properties in most cases, many engineers assume an equivalent fluid pressure for estimating lateral forces acting on the wall. Weights generally assumed for the hypothetical fluid range from 25 to 34 lb. per cu. ft. The American Association of State Highway Officials requires structures for retaining earth fills be designed for a minimum equivalent fluid pressure of 30 lb./cu. ft.* Assuming an equivalent fluid pressure of 33 lb. and a wall height of 12 ft. as in Fig. 1, where somewhat severe backfill conditions were assumed: P = ½ x 12 x 12 x 33 or 2,376 lb. This pressure as before acts at ⅓ the wall height "h" above the base.

Surcharge Loads

Sometimes surface loads are supported on the retained embankment so close to the wall that they cause an increase in pressures exerted by the unloaded backfill. Highways, railroad tracks, or buildings located very near the wall are typical installations causing surcharge loads. Impact from moving loads need not be considered, as the earth fill damps out vibration quite effectively. However, an allowance should be made for a unit load equivalent to that obtained by a reasonable distribution of the weights of these structures. The effect of the surface load is compensated for by an added depth of earth that imposes the same unit vertical pressure.

For highway traffic within a distance from the wall of one-half its height, Standard Specifications for Highway Bridges of the AASHO, require a surcharge earth fill of not less than 2 ft. The Manual of the American Railway Engineering Association recommends that in calculating surcharge due to track loading the entire load be distributed over a width of 14 ft. for a single track. A lengthwise distribution of 5 ft. is usually assumed for a locomotive axle load and the unit surface pressure computed by dividing the Cooper's E value by 5 x 14 sq. ft.

The effect of a surcharge fill of height h′ on the lateral pressures exerted by the level backfill of wall height "h" is indicated in Fig. 2.

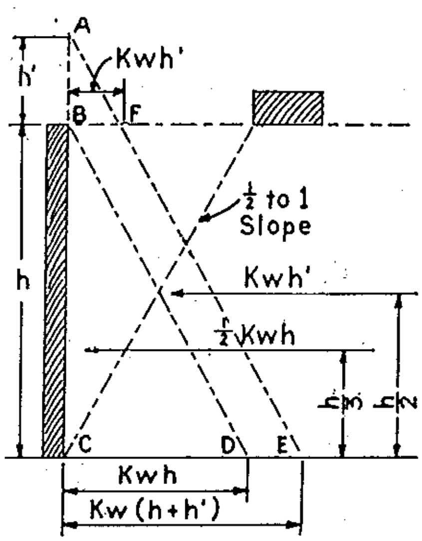


FIGURE 2

The total horizontal pressure at the top of the wall is wh′ and at the bottom w(h+h′). Total pressure on the wall therefore is represented by the combined areas of the triangle BCD and parallelogram BFDE. Centers of gravity through which the horizontal pressure of the level backfill and the surcharge act are indicated in Fig 2.

It is quite doubtful if vertical or lateral pressures under a load extend beyond the boundaries of a ½ to 1 slope. Some tests conducted on sand have indicated such a boundary to be the limit. Thus the surcharge effect of surface loads at a distance greater than ½ the height from the wall generally can be neglected.

Cantilever Walls

Low walls of treated timber depending for their stability on the guide piles or posts acting as cantilever beams fixed in the underlying soil are often used for retaining low fills. The cantilever wall is not adapted to very weak soils in which little resistance to lateral loads can be developed in the soil by the supporting piling or uprights. In such cases bracing or tiebacks should be provided. Where lateral support depends on cantilever action alone, conservative practice usually limits wall heights to about 7 ft.

The resistance to lateral loads on piles or posts embedded in the earth and acting as cantilever beams is important in designing these unbraced walls.

The forces acting on a cantilever wall post, and pressures developed in the soil by the laterally loaded post are shown in Fig. 3. For moderate depths of set, the point about which the embedded post tends to rotate is approximately two-thirds of the depth of embedment below the surface of the ground. This is the point where passive earth pressure changes direction.

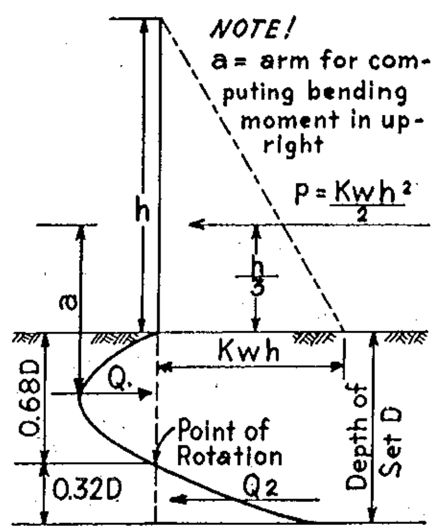


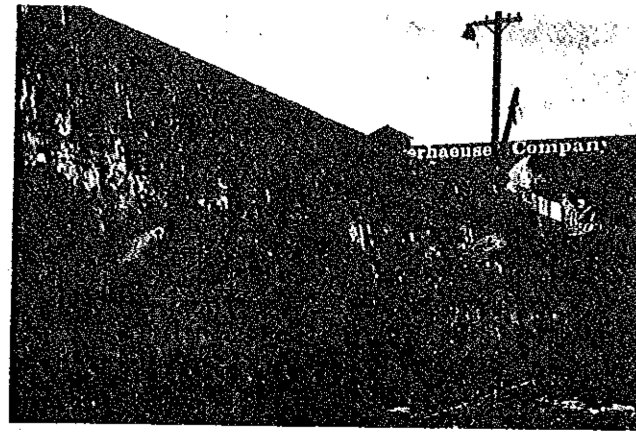
FIGURE 3

*"Standard Specifications for Highway Bridges" — American Association of State Highway Officials.

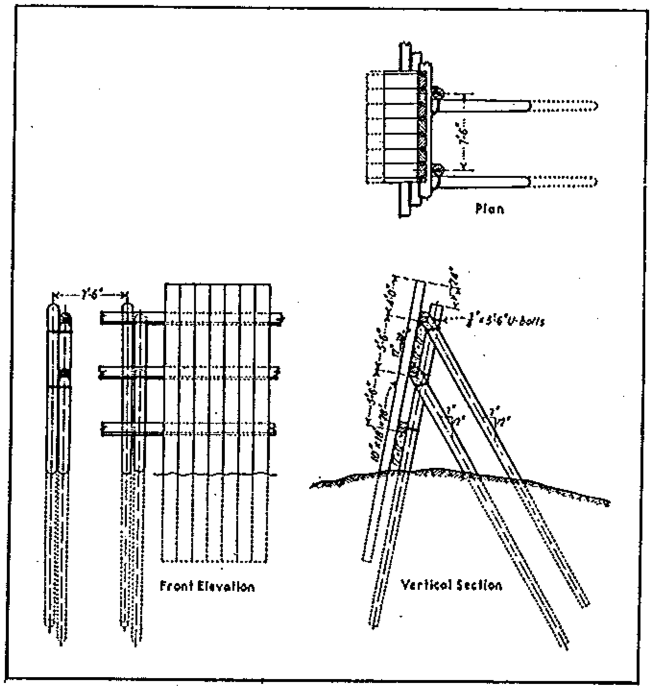
paper mill. The site of the second mill is protected by timbered retaining walls from the flood waters of the Snohomish River.

The face of the bulkhead comprises treated Douglas fir sheet piling 18 in. wide, varying from 10 to 16 in. thick and 24 to 40 ft. long in accordance with the height of fill. These piles were surfaced on four sides and grooved to receive 3 by 5 ft. splines before treatment. Other design details are apparent in the accompanying photographs and drawings.

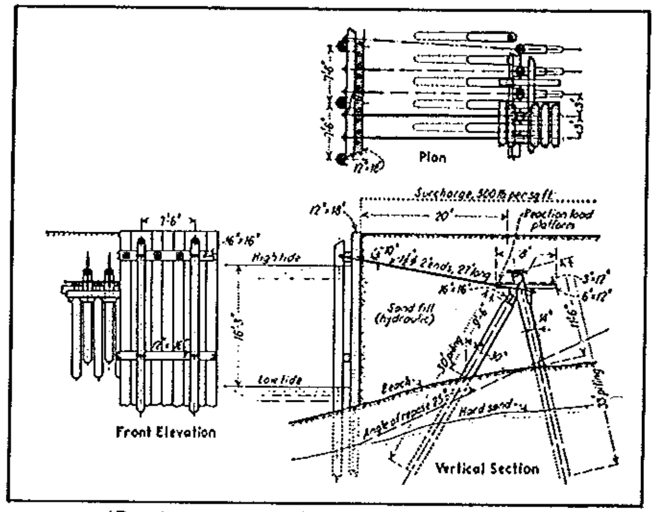
The seawall construction is somewhat similar to that of the bulkheads except that it is made up of three lines of wale timbers supported by diagonal bracing piles of circular cross section, driven behind the two upper wales. The face of the wall consists of splined creosote-treated timber sheet piling. One of the interesting procedures that was carried out during the first six months following completion of the seawall, was the periodic tightening of all steel fastenings to compensate for any shrinkage in the timbers.



This seawall at Everett, Wash., has fulfilled the expectancy of its designers and builders by protecting shore property from the wave action of battering storms for more than 30 years.



These drawings illustrate the sturdy design of the seawall built to protect the Weyerhaeuser mill property from wave action across some 20 miles of open seawater at Everett, Wash. Note the design includes splined heavy timber sheet piling fastened to 3 lines of timber wales which in turn are supported by a system of round timber piles driven at an angle.



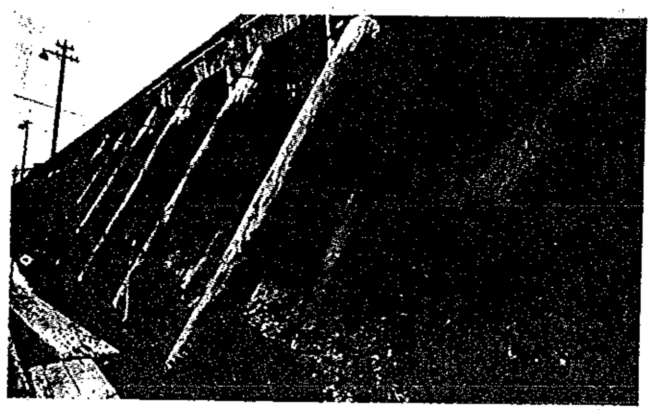
(Drawings courtesy of Engineering News-Record)

The relatively simple design drawings of the Weyerhaeuser bulkhead were developed from modifications of earlier types to provide better durability. Some 4,300 lin. ft. of pressure-creosoted timber bulkheads of this type were built in 1935 and 1936 and were reported in good condition after a thorough inspection 28 years later.

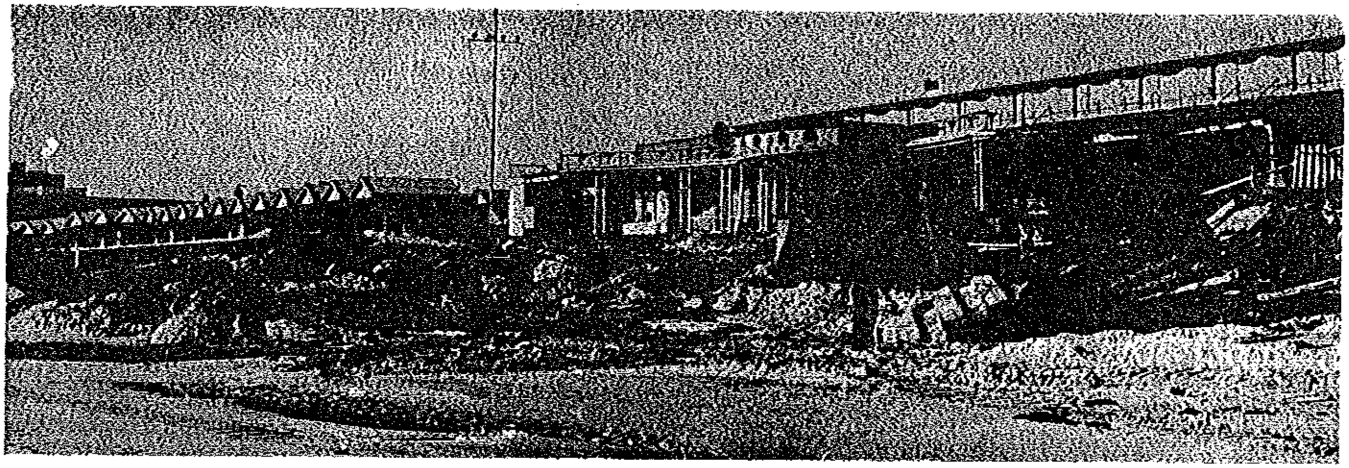
Exposed portions of the tieback rods and other steel fastenings were protected with bituminous coatings against heavy corrosive action of seawater. Following the prime coat, tieback rods were spirally wrapped with burlap and a second heavy coating of bitumastic material was applied.

Seawall Stops Erosion; Costs $54,600 Less

One of the best examples of a low-cost pressure-treated timber bulkhead successfully designed to prevent very heavy beach erosion, especially during hurricanes, is the 9,100 ft. retaining wall built about eight years ago at Maryland's Naval Station at Patuxent River,



The pressure creosoted Douglas fir piles were driven at an angle to provide diagonal bracing for the wall itself. The face of the wall consists of creosoted timbers splined in the same manner as those of the bulkheads.



Collapse of inadequately designed seawall at Virginia Beach, Atlantic Coast, during March 1962 storm permitted tidal flow to badly erode beach and damage ocean front structures. Adjacent area behind properly built seawall remains relatively undamaged.

to protect a vulnerable section of a 16,000 ft. beach.

Primary elements of this installation comprised 1,792 Class B 40 ft. and 205 Class A 50 ft. pressure-creosoted timber piles. These were driven in pairs, one vertical and the second as a batter. The piles were bolted together with ¾-in. zinc-coated bolts and washers, to provide added stability for upper and lower lines of 10 by 10 in. Douglas fir wales which had been framed and incised before treatment. The wales were fastened to the shore side of the pile clusters.

Treated sheet piling 4 by 12 in. tongue and groove planks formed the face of the wall: 10,635 pieces 16 ft. long and 1,700 pieces 22 ft. long. These were driven and fastened to the wales with four zinc-coated ½ in. by 10 in. spikes, two in each line of wales.

Timber was chosen for this bulkhead because of its economy, rugged serviceability and dependable long-life. Savings in first costs compared to estimates for a stone revetment amounted to $54,600 and the estimated additional saving in upkeep was approximately $900 a year.

Additional stability of the bulkhead was assured by fastening it to a series of anchor piles driven well back of, and at varying distances from, the face of the wall. The anchor piles were spaced about 10 ft. apart and bracing consisted of 8 by 8 in. treated timber struts and 1¼ in. steel tie rods.

Aftermath of Atlantic's Worst Storm

Repeated storms and hurricanes along the Atlantic coast have proved the value of well-designed and well-built treated timber bulkheads for the protection of shore properties. The three-day storm of early March, 1962 rated as the worst blow in 50 years, whipped coastal areas from Florida to New England. The storm was generated by strong winds that blew over the Atlantic for a long time and set in motion currents and waves of ever-increasing height and intensity which broke on shores and beaches with growing destructiveness. Spring tides added to the flooding. Destruction in the New York City area exceeded that of Hurricane Donna in 1960 and more than 100 Long Island homes were destroyed. Damage to New Jersey and Delaware communities amounted to an estimated $100 million.

The protective effectiveness of treated timber bulkheads and seawalls in that storm was well demonstrated in a short section of Virginia Beach where homes remained relatively undamaged, but adjacent homes, unprotected by a timber seawall, toppled when their foundations were undermined by the heavy seas.. Some poorly designed seawalls of other materials at Virginia Beach were undermined and buckled or overturned allowing houses to topple over. The beach was viciously chewed up as well and estimated damage ran to about $25 million.

As a direct aftermath of that unprecedented 1962 storm, planning officials at Virginia Beach met and urged the construction of treated timber bulkheads or seawalls on beachfront properties and recommended that new houses should be built on substantial timber pile foundations.

For Railroads and Highways

Crib retaining walls of treated timber have been in service on American railways for half a century and more. Many of the older installations also are to be found along state highways. Among the most recently established standards for the design and construction of crib-type walls is that of the California Division of Highways, Department of Public Works, which was adopted and issued early in 1962. Detailed plans include walls ranging in height from 4 ft.-8 in. to 22 ft. ■

In order to give this important subject the comprehensive coverage it deserves, the September issue of WPN will contain a second article on earth retaining structures. Part II will cover the elements of design, and engineering specifications recommended in the construction of retaining walls, bulkheads and seawalls.

TREATED TIMBER RETAINING WALLS

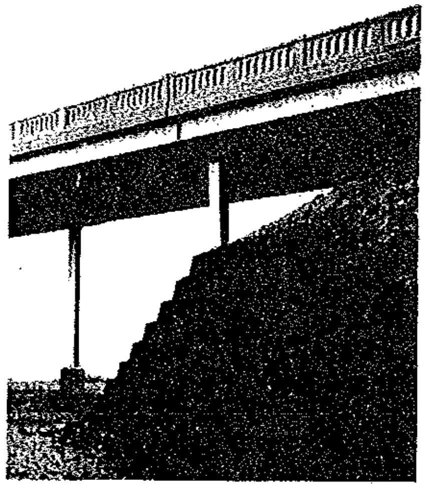
f = Allowable working stress in extreme fiber in bending for the grade of lumber used

Permissible working stresses for sawed timbers and lumber are published for the species of wood from which structural or stress rated grades are manufactured. The great bulk of structural timber, i.e., that furnishing grades to which definite allowable working stresses are assigned is manufactured from the Southern pines and from the West Coast woods, Douglas fir and hemlock.*

Allowable working stresses for round timbers have not been published. Round timbers, however, have two distinct strength advantages. A circular timber has a form factor of 1.18 which means it is 18 per cent stronger in bending than a rectangular timber of comparable grade with the same section modulus. A round timber pole or pile, too, in practically all cases has a high proportion of the basic strength of its species. Knots have only one-half the effect on the strength of natural round timbers as they do on sawed sections. Results of numerous tests show that full size round timber poles develop practically the full bending strength of the clear wood.

A high strength grade therefore can be assumed for round timber piles or posts. Few if any knots occur in the lower portion of the post where greatest stress develops. An allowable extreme fiber stress in bending of 1,700 psi is conservative for comparable grades of Southern pine or Douglas fir. Because of the form factor this can be increased by 18 percent, and the allowable stress of the round timber can be taken as 2,000 psi.

*Standard grading rules for the Southern pines are published by the Southern Forest Products Association, P. O. Box 52468, New Orleans, La. 70152, and for Douglas fir and western hemlock by the Western Wood Products Association, 1500 Yeon Building, Portland, Ore. 97204.



This creosoted timber crib wall was built at Roscoe, S.D. in 1936 by the South Dakota State Highway Department.

Where the backing plank or sheathing is vertical, as in sheet-pile walls, usually wales are placed near the top, and sometimes at intermediate levels. These wales provide supports for the vertical sheathing and transmit the load to the guide piles. The vertical sheathing pieces are beams fixed at the lower end by penetration in the soil and simply supported at the wale. For all practical purposes, however, the fixed end effect can be ignored and the pieces considered as beams simply supported at the ground and at the wale.

Sheathing supported at the ground and at a wale along the wall top is

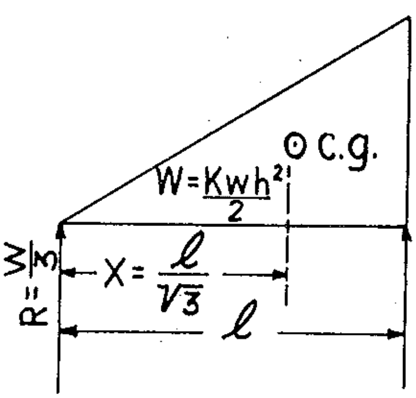


FIGURE 7

loaded similarly to the beam in Fig. 7. Load on a 1-ft. width of sheathing increases from 0 at the top to wh at the bottom.

The maximum bending moment occurs at a distance $x = \frac{h}{\sqrt{3}}$ or 0.577h below the top, and for a simple beam loaded as shown when l is replaced by h is:

$$M = \frac{Wx}{3h^2}(h^2 - x^2)$$

Where wale levels are above ground or below the top of wall the condition is that of a beam overhanging its supports and the maximum bending moment is reduced by the overhang. Because these supports are not rigid, the assumption of end support is conservative, and it is doubtful if further refinement is justified in practice.

Generally walls more than six or seven feet in height are tied back to anchors, or to piling driven behind the wall. Where sheet-pile walls are supported by guide piles and wales, bracing is sometimes provided by batter piles driven usually back of but sometimes in front of the wall. Their tops are through bolted to the guide pile at sufficient height above the base to provide support against the back fill thrust.

The most common method of tying back consists of rods or cables extending from the wall to anchors or piles placed at some distance back. The tie rods are usually fitted with turnbuckles so they can be tightened sufficiently to hold the wall in alignment when the back fill is placed. These tiebacks supply supports and the wall becomes a simple or overhanging beam with a

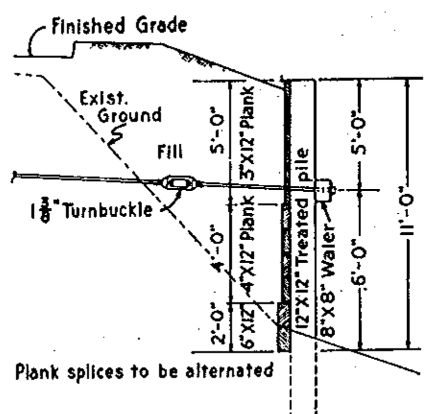


FIGURE 8 Section of pressure treated wall built by the Oregon State Highway Commission showing tieback rod and turnbuckle.

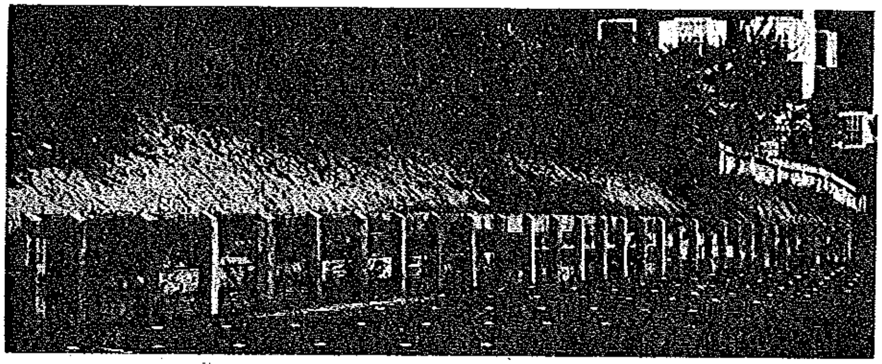
triangular load. Because thrusts near the top are light, tie rods are placed at some distance below the wall top to adjust reactions as desirable, and also to reduce bending in the guide piles.

Timber Crib Walls

Pressure-treated timber crib walls with cells or compartments filled with suitable material, either earth or rock, can be founded satisfactorily on almost any soil. Base widths are generally such that the foundation load is distributed over sufficient area so that unit pressures are small.

Cribs may be erected by unskilled labor and with simple equipment. The space or opening between face members, or stretchers, should not be wide enough to permit the fill material to spill through the opening. With dirt filling, openings should be somewhat less than ⅔ the horizontal width of the face member, since earth fills usually require a slope of 1½ to 1.

Designs of crib walls are empirical. Experience has developed conservative rules for design and construction. Faces of these walls may be built on any desired batter or they may be vertical. Many timber cribs built by railroads have a face batter of 1 to 4. Slightly greater base widths should be used for cribs with vertical faces than those with appreciable batter.



Pressure-treated wood retaining wall at Town Club in Portland, Oregon.

The following ratios of base width to height are generally used:

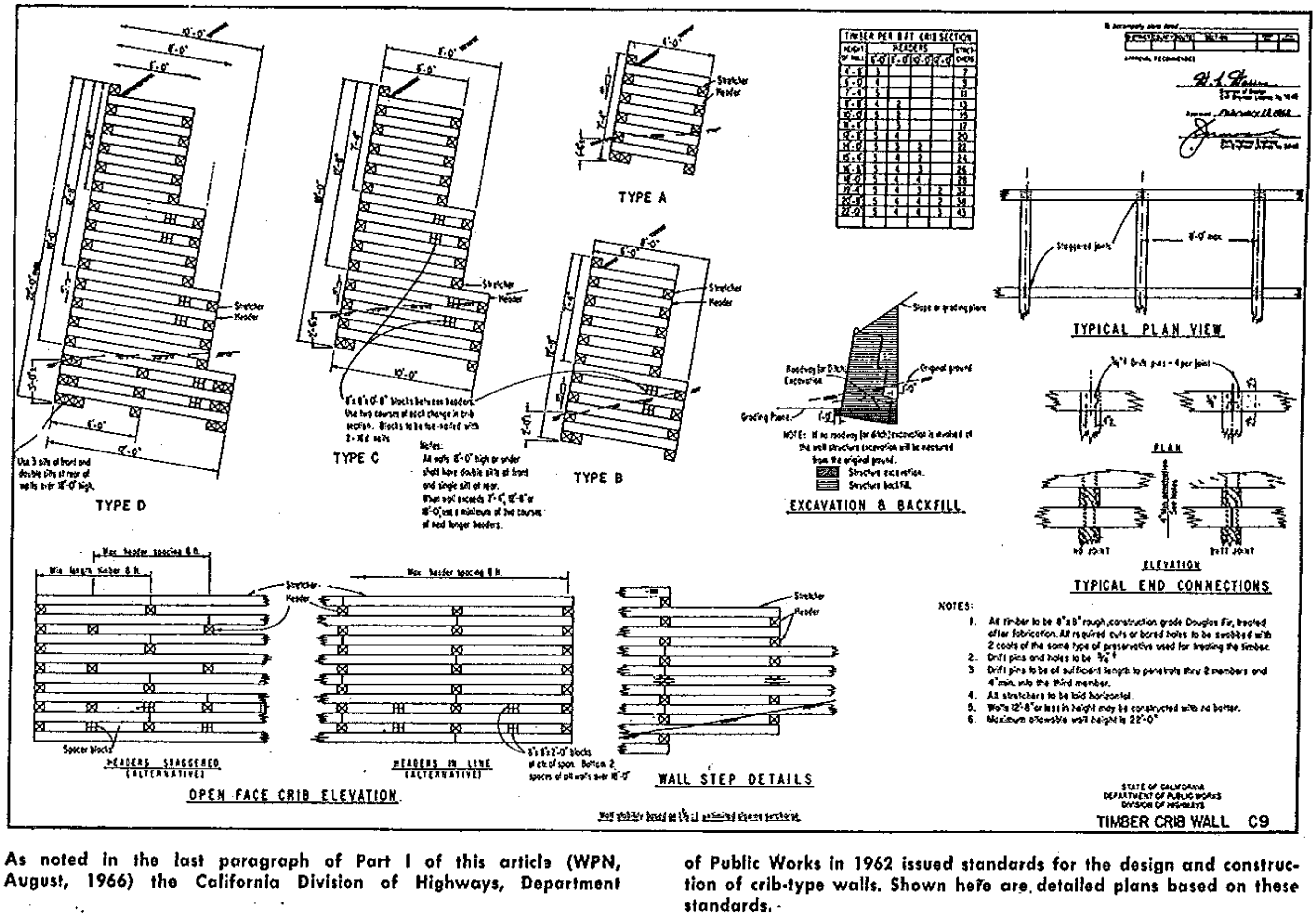
For little or no surcharge, 50 per cent.

For cases of light surcharge, but where highway or railroad loads move over the fill, 50 to 65 percent depending on the weight of load and its distance from the wall.

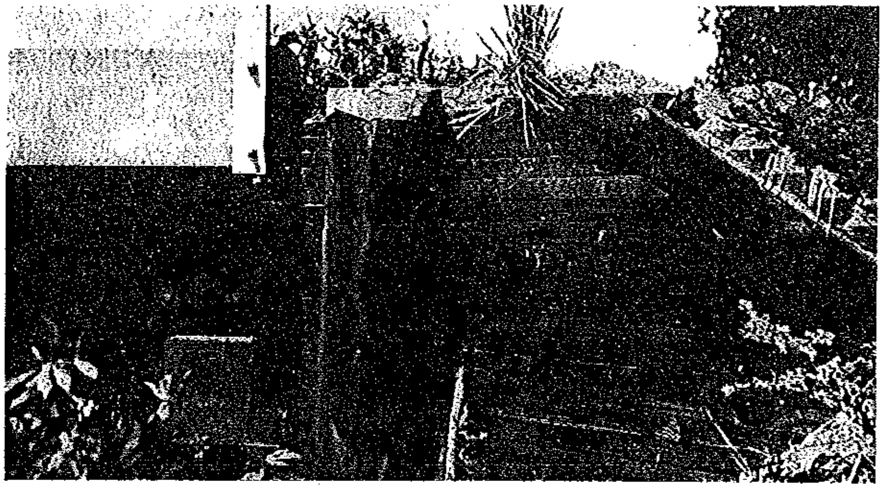
In cases of heavy surcharge, at least 65 percent.

Backs of walls are usually stepped to permit reduction of base widths at frequent height intervals. The minimum base width should be 4 ft.; nor should the top width be less than this for any except very low walls.

All cutting, framing, and boring of the timbers should be done before pressure treatment. Treating plants are equipped to do all necessary graining, boring, cutting, etc., more economically than field forces do the same work. Framing prior to treatment avoids field cuts that may expose the untreated core of the timber and thus permit decay, whereas preframing assures adequate protection. ■



As noted in the last paragraph of Part I of this article (WPN, August, 1966) the California Division of Highways, Department of Public Works in 1962 issued standards for the design and construction of crib-type walls. Shown here are detailed plans based on these standards.



This laminated backwall and wings of pressure treated 2x4's was designed and built about 13 years ago by F. R. Rankin, county engineer of Reno County, Kansas.

The depth of set needed to prevent a lateral force acting at a given distance above the ground from causing objectionable deflection is computed by the formula:

$$D = \frac{2.37P + \sqrt{(2.37P)^2 + 10.56PHSB}}{2SB}$$

Where:

- D = Depth of embedment in ft.
- P = Horizontal thrust in lb.
- H = Height above ground surface at which P acts
- B = Average diameter of round or diagonal of square post in ft.
- S = Average soil pressure above point of rotation, psf

The Outdoor Advertising Association of America, Inc., gives a general classification of soils for use where only a visual inspection is practical. Soils vary in their classification with changes in moisture content through the year. The worst condition at a site should be anticipated.

The definitions good, average, and poor soil listed in the OAAA Engineering Design Manual are as follows:

Good soil is compact, well-graded sand and gravel, hard clay, well-graded fine and coarse sand, decomposed granite rock and soil. Good soil also should be well drained and in locations where water will not stand.

Average soil is compact fine sand, medium clay, compact, well drained sandy loam, loose coarse sand and gravel, and medium clay. Average soils should drain so that water does not stand on the surface.

Poor soil includes soft clay, clay loam, poorly compacted sand, clay containing a large amount of silt and vegetable matter. These soils will hold moisture and absorb great quantities of moisture when wet. Usually soils of this type are found in low lying areas, and in areas where water stands during the wet season.

Pressure-treated crib-type retaining wall at residence in Portland, Oregon.

The Engineering Design Manual states also that study and analysis of many tests reveal that moisture content and its effect on the soil is a greater factor in determining stability than is a fine division of soils. "Relative stability of uprights [cantilever supports for outdoor signs] determined on this basis is much more uniform than those based on fine divisions of soil composition."

Horizontal Resistance to Soil

There is relatively little available information on the relationship between horizontal resistance of a soil and its safe bearing value. Investigators have noted that the horizontal resistance of a soil increases very rapidly in the first two feet or so of depth. Increases continue for moderate additional depths but at a slower rate. Tests have shown that considerably higher values can be assumed for resistance to horizontal loads than for the bearing resistance considered safe for spread footings. Data collected on some important construction indicate that the horizontal resistance of an ordinary soil can be taken conservatively as 1½ times that permissible for spread footings on the same soil.

Typical of pressure-treated wood retaining walls found in residential areas, garden of residence in Menlo Park, California.

Fig. 4 shows a typical design for low walls supported by cantilever uprights and lists sizes of material, spacing of posts for the different heights, and also depth of embedment for the supporting posts.

Fig. 5 is the design recommended in the Manual of the AREA for a much heavier wall supported by minimum 12 and 14-in. diameter piles. The design covers cantilever walls up to 9 ft. in height. The design is based on usual sizes of pressure treated material carried in railway stocks. The recommended depth of embedment anticipates the worst conditions likely to be found along railway rights of way. Bulkheads and cantilever retaining walls conforming to this plan have been used at many locations. For many low walls, however, the lighter design is equally satisfactory and more economical.

For posts set at moderate depths, the point about which the post tends to rotate when acted on by transverse forces is at approximately ⅔ the depth of set below the surface. The point of fixity for computing the bending moment in the upright is thus below and not at the ground surface. Assuming the point of fixity for the cantilever at ⅓ the depth of set seems reasonable for determining the arm for computing the bending moment in the post.

The pressure acting on a lineal foot of cantilever wall is the uniformly increasing load indicated by the triangle ABC in Fig. 6. This load acts through an arm $\left(\frac{3}{h}+\frac{3}{D}\right)$ and is multiplied by S, the distance in feet between posts, to obtain the total thrust against each post.

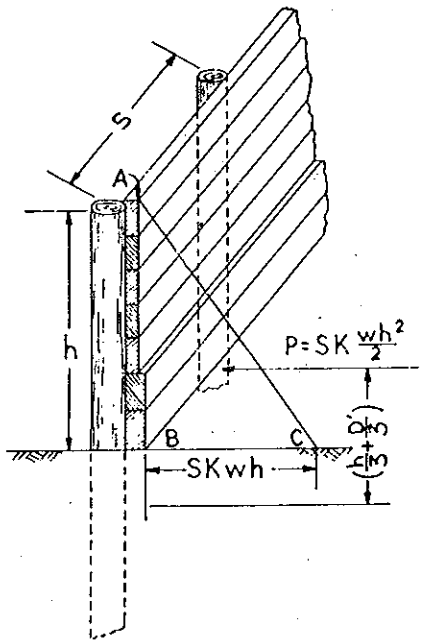


FIGURE 6

The bending moment on an intermediate post is:

$$\frac{SKwh^2}{2}\left(\frac{h}{3}+\frac{D}{3}\right)$$

The horizontal backing plank generally are continuous beams on elastic supports with a uniformly distributed load that increases directly with the depth of the plank below the top of the wall. The uniformly distributed load per lineal foot on any plank is wh″ where h″ is the depth in feet below top of wall, and w = weight per cu. ft. or lateral pressure per cu. ft. of the backfill. In most cases decreasing plank thickness as top of the wall is approached is an economy.

For calculating thickness of plank required at the different levels the bending moment should be taken as $\frac{wL^2}{8}$ since many of the planks will be continuous over two spans only. Equal span lengths are usually maintained and the following formula is convenient for computing plank thickness required at the different levels:

$$t = 3S\sqrt{\frac{wh}{fb}}$$

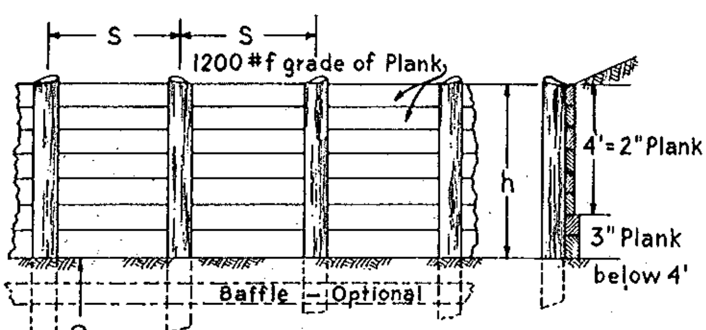
Where

S = Distance in feet C to C of supports

wh = Load in pounds per lineal foot

t = Required thickness of plank (inches)

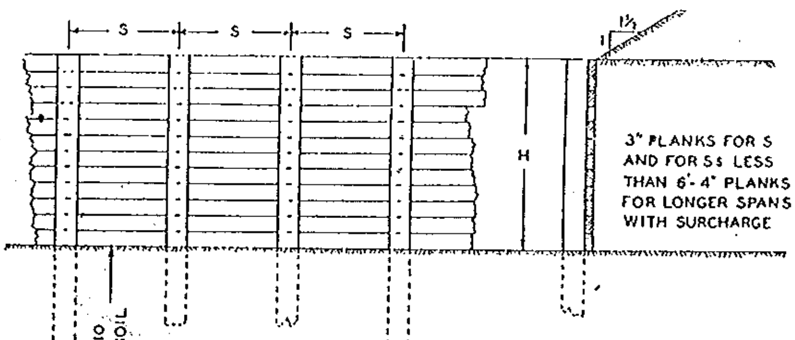
b = Width of plank (inches)



Equivalent fluid Pressure = 34 lb. p.c.ft.

Height of wall ft.	Dia. Rd. Posts inches	Spacing C.C. of Posts ft.	Posts depth of set ft. 2000 lb. Soil	1500 lb. Soil	1000 lb. Soil
3	6"	6'	3.5	4.2	6.0
4	6"	4'	4.0	4.5	6.6
4	8"	6'	4.0	4.5	6.6
5	8"	4'	4.0	5.0	6.6
5	8"	5'	4.4	5.5	
5	9½"	5'			7.5
6	9½"	4'	5.4	6.6	9.2
6	9½"	5'	6.1	7.8	
6	10½"	5'			11.0

FIGURE 4 Low Cantilever Walls



IF 12" MIN DIA PILES ARE SPECIFIED

HEIGHT H	SPACING S	Ss
9 FT	2' 6"	
8 FT	3' 0"	
7 FT	4' 0"	
6 FT	5' 6"	2' 6"
5 FT	8' 0"	3' 6"
4 FT	10' 0"	5' 6"
3 FT OR LESS	10' 0"	10' 0"

IF 14" MIN DIA PILES ARE SPECIFIED

HEIGHT H	SPACING S	Ss
10 FT	2' 6"	
9 FT	3' 0"	
8 FT	4' 0"	
7 FT	6' 0"	2' 6"
6 FT	8' 0"	3' 6"
5 FT	10' 0"	5' 6"
4 FT		9' 0"
3 FT		10' 0"

FIGURE 5 Railroad-type Cantilever Wall. NOTE: For walls without surcharge, use spacing in Column S; with surcharge use spacing in Column SS.

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