A "NO PRESSURE" TIRE WALL: A CASE HISTORY

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ABSTRACT

This paper describes how re-cycled materials were used as part of a creative and economical solution to a challenging engineering problem. A client wished to backfill the basement area of one lot, yet avoid imposing any additional lateral load on the un-reinforced concrete basement wall of the adjacent building. In response, Creative Engineering Options, Inc.,(CEO) designed a retaining system consisting of recycled rubber tires. The new wall was built 75 to 150 mm (3 to 6 inches) from the existing concrete wall. It retained a compacted miscellaneous backfill, without imposing any additional load on the concrete wall and supported an asphalt paved parking lot. The tire wall accommodated variations in existing site grade and varied between about 1.22 and 3.05 meters (4 and 10 feet) in height. It consisted of two rows of recycled tires stacked one behind the other.

The design incorporated a variety of imported materials, obtained "free" from other construction sites, into an average wall weight of 2,994 kg/meter (2,000 pounds per running foot) to resist lateral movement. The weight was developed by means of a free-draining crushed rock backfill which allowed for drainage down to a basal drain system beneath the wall. Completion of the wall and backfilling allowed for the placement of an asphalt pavement surface to support vehicular traffic and parking. No visible evidence of settlement or lateral movement has been observed in the approximately three years since construction was completed.

INTRODUCTION

The challenge was to develop a retaining system capable of supporting both a lateral and vertical loading, without transferring any load to the adjacent building wall. The client owned a multi-story concrete office/warehouse building fronting onto a main thoroughfare in downtown Seattle, which was being used as a retail outlet for truck parts. He also owned the adjacent lot, which had once been occupied by a similar structure. The building on the "empty" lot had been burned virtually to the ground, but some of the basement area was being used as a temporary storage deck. The deck was constructed on a series of large timber columns which were founded on small concrete pads set in the soils filling the lower part of the old basement area.

The client's primary concern was that the existing structure's basement walls were constructed of un-reinforced concrete and already exhibited numerous cracks, due to

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vertical settlements during the buildings' lifetime. By backfilling the adjacent basement area, the client could take advantage of the additional roadway frontage along two sides of the lot and provide on-site parking for customers, in an area notorious for a lack of parking. A previous geotechnical engineer had provided a conventional design for a reinforced concrete retaining wall. The retaining wall was required to support an estimated 3.05 meters (10 feet) of miscellaneous import fill material. As a result, the original geotechnical engineer had developed a series of conservative design parameters for a "sturdy" retaining wall. However, the client felt the system was too expensive and the design too conservative. CEO's initial involvement was as a value engineer, to evaluate the initial design and offer potentially less expensive options.

PROJECT DESCRIPTION

Each of the two lots involved in this project measure approximately 18.3 meters (60 feet) in width and about 33 meters (108 feet) in length. The southernmost lot was occupied by a one-story concrete building with a below-grade basement level measuring approximately 3.05 meters (10 feet) in height. The floor and roof were supported on the perimeter walls and two rows of interior columns on a 6 meter (20 foot) square grid pattern. The basement level access, from the paved alley along the eastern side of the property, was a roller door at the bottom of a depressed ramp. The basement level, in use as a truck parts storage facility, was subject to considerable activity on a day-to-day basis. The upper floor, at street grade, was a retail facility for the sale of truck parts.

The concrete basement wall consisted of un-reinforced, or at best minimally reinforced, concrete construction and was 25.4 centimeters (10 inches) thick. It showed visible evidence of movement-related damage in the form of vertical and diagonal cracks extending up through the wall from floor to ceiling. Several of the cracks were of sufficient width to have required caulking in the past.

The adjacent lot, where the original building had burned down, was essentially "bowl" shaped as a result of partial filling of the basement space. The western end of the lot acted as a temporary storage deck. The deck was constructed from timber planks supported on large timber columns set on concrete "pads" set into the in-place soils. These timber columns, apparently part of the original structure, had also been subject to a considerable degree of fire damage. The site was also being used as a trash dump by neighbors, a factor which did not add to the value or usability of the property.
The approximate layout of the site, including both the existing structure and the "empty" lot, is depicted in Figure 1, and is pictorially depicted in Figure 2.

The client believed this "basement' space would be more useful as additional parking space for the sales facility, in an area where every parking space is at a premium. He thought that it would be helpful to remove the existing timber structure and to backfill the basement back to the existing street grade. Once filled, the surface could be asphalt paved. Unfortunately, this idea did not take into account the potential loads that would be applied to the existing un-reinforced wall.

The client retained the services of a reputable local geotechnical consulting company to perform an evaluation of the in-place conditions and, on the basis of this evaluation, provide recommendations for a suitable retention system. The evaluation was of limited scope and detail, but adequately provided necessary geotechnical design parameters for design and construction of a new reinforced concrete retaining wall and site backfill.

INITIAL SITE STUDY RESULTS

The first step in the initial study by the original geotechnical engineer was to hand dig a shallow pit next to the base of the existing buildings' northern wall at about the mid-point of the site where the new wall would be of greatest height. This pit exposed soft to stiff clayey silts and loose silty sand backfill against the base of the wall. These soils were classified by the Unified Soil Classification System (USCS) as an ML or CL and an SM, respectively.

Beneath the backfill, and beneath the existing buildings' foundations, the soil was found to be a hard clayey silt. This latter material was classified by the USCS as an ML. The geotechnical engineer also indicated that, from his research, the soils believed to underlie this property consisted predominantly of glacially overridden silts and clays. These soils are generally described as the Lawton Clay in this area.

According to Galster and LaPrade (1991), these soils are typically a Glaciomarine Drift (GMD), which is a heterogeneous mixture of the full range of grain sizes from clay to boulders. As clay is often a common constituent in this material, it often resembles Lodgement Till, except that it exhibits a blocky texture rather than the more massive characteristics of a Lodgement Till.

In the Seattle area, the GMD is of pre-Vashon age and has been glacially overconsolidated. As a result, the GMD exhibits essentially the same engineering characteristics as Vashon Till, and are tabulated below:

Wet Unit kg/M^3 (pcf)	USCS	N-Value	Allowable Soil Bearing kPa (tsf)	Permeability cm/sec (Ft/Day)	Plasticity
2,080 to 2,400 (130 - 150)	ML, SM SP	50 to 100 +	400 to 1,000 (4 to 10)	10^{-3} - 10 (10^{-7} to 10^{-3})	Non Plastic

As a result of this limited field study and site assessment, the geotechnical engineer settled on the use of a reinforced concrete retaining wall as the best means of restraining the basement area backfill without imposing any load on the adjacent building wall. He based his design on the use of a pea-gravel or crushed-rock backfill wedge next to the new wall. This material was recommended to avoid the need for any significant compaction and the added weight of a roller that would be necessary to adequately compact the backfill. This granular "un-compacted" wedge was to extend up from the base of the wall at an inclination of 1.5H:1V. The design used a lateral equivalent fluid pressure of 881 kg/m^3 (55 pcf) as the design pressure.

The new reinforced concrete wall was to be eight inches thick and built directly against the existing wall, relying on the presence of the existing structures' footing to provide lateral restraint against sliding. The new wall footing was only to be 46 cms (18 inches) wide and would, therefore, provide little sliding or overturning resistance. A pictorial depiction of the proposed wall and backfill system is presented in Figure 3.

On review, the owners believed that this system did not adequately prevent loads being transferred into the existing structure, particularly into the already cracked basement level wall. As can be seen from Figure 3, even a very small amount of wall rotation will develop added lateral pressure on the un-reinforced existing wall. The owners took the position that, over time, the addition of lateral loads to the existing building wall would probably cause significant damage. Therefore, they decided to seek a second opinion and "value engineer" this design.

DEVELOPMENT OF A SECOND OPINION

CEO was referred to the owners by the structural engineer as a firm capable of providing innovative options for the wall. Our first step was to evaluate the information already obtained and assess the initial reinforced concrete wall design. On the basis of this evaluation, our opinion was that, to avoid overloading the existing basement wall, it would be necessary to separate the original wall from any new structure.

The construction of the proposed reinforced concrete wall would, in our opinion, result in the development of lateral loads on the adjacent building over time, since the new wall was to be formed and poured directly against the old building wall. Furthermore, we felt that the proposed wall foundation was inadequate to provide sufficient restraint against overturning, a motion that would clearly add load to the existing building. In our opinion, the implications to the existing structure were clearly detrimental and likely to result in a greater degree of damage to the existing wall structure over time.

On the other hand, creating a small void between the two walls would provide space for wall flexure and movement over its lifetime without adding any new load to the existing wall. This immediately raised the issue of how to form the exterior of a concrete wall in such close proximity to the existing structure. Clearly, this was not an option and essentially eliminated the reinforced concrete wall from consideration. Other potential systems considered included a geogrid reinforced backfill and a masonry block wall, concrete ecology blocks, and gravel backfilled recycled rubber tires.

Since CEO had been involved in the design and construction of low-cost retaining systems for several years, we were able to draw on our previous experience to develop an innovative and inexpensive option for this site. The use of geogrid reinforced backfill and a masonry block wall was clearly acceptable, but the cost of materials proved to be almost as expensive as the original wall design. Concrete ecology blocks were a relatively economic material, but the adequacy of the concrete was in question since the blocks are constructed from old and waste concrete.

In addition, to adequately resist overturning, it was necessary to "lean" the wall back toward the backfilled area of the basement, creating a relatively large gap along the top of the wall. A relatively large source of block was also necessary, and none of the local concrete companies would guarantee that adequate blocks would be available when needed. As a consequence, a wall constructed of gravel backfilled rubber tires was used.

The use of stacked rubber tires to achieve the separation between the existing structure and the new construction also allowed us to provide a "wall system" that would restrain the lateral backfill soil loads as well as any compaction equipment surcharges, without undergoing any appreciable distortion or movement. We believed the tires could be placed simply and economically with a small work crew, that the raw materials (tires) would be of low cost, yet ecologically acceptable, and they could create a wall of sufficient proportions to resist the imposed lateral and vehicular surcharge loads. Indeed, the primary concern was related to maintaining a sound structure while backfilling.

HISTORICAL BACKGROUND

Rubber tires were used to construct several crib-type retaining walls and anchored walls on the M62 motorway near Bradford in England in 1982. These walls enabled the motorway designers to steepen embankment side slopes at a relatively low cost with an expectation of long-term stability (Dalton & Hoban, 1982).

Rubber tires for wall and erosion control structures have been used for several years by the U.S. Forest Service. For example, tire-faced walls were used in constructing roadway embankments in the Plumas National Forest between 1990 and 1992 (Steward, 1992).

Because of the push to use recycled materials in local government and federally funded projects, and because rubber tires seem to be so difficult to dispose of, they have been subject to extensive analysis, particularly as a source of materials for use as a shredded lightweight backfill. The study, including lysimeter testing for environmental evaluation, was performed for the Wisconsin DOT by Professor Tuncer Edil (Edil & Bosscher, 1992). Since the evaluations indicated the material was environmentally inert, they became more attractive as a source material for wall construction.

Petrovich, Nottingham & Drage (1994) built a test wall in Alaska as a research project to assess the potential for movement in the wall during construction and to evaluate the viability of recycled tires as wall construction elements. Their research indicated that walls as high as 12 meters (40 feet) could be constructed in this manner, but that they would require the use of a geotextile or geogrid as a backfill reinforcement.

For a wall of about 3 meters (10 feet) in height the estimated cost per square foot in this study was approximately $12 to $15. With increased wall height, the costs increased to about $35 to $38 per square foot for a 12 meter (40 foot) high wall, based on Anchorage materials and labor costs. Clearly, these costs, even at Alaska prices, are competitive.

More recently (Lorang, 1996), used large heavy equipment tires as a stabilizing material in a New Mexico irrigation canal periodically subject to high velocity flows. Engineers, Inc., designed and installed this canal bed protection system using ore hauler tires staked into the canal bed with long steel rails and backfilled with native earthen materials.

CEO has also designed and constructed a series of tire walls to protect residential property slopes against erosion and slippage and for repair of a severely eroded fill slope. The latter structure consisted of a two-stage wall to re-construct the damaged slope.

RE-CYCLED TIRE WALL DESIGN

The first step in our wall design process was finding a suitable source of used tires. We contacted Bolser International, a local supplier of new tires and a recycler of old tires was interested in the engineered tire wall system. It provided an additional outlet for old used tires. During discussions with Bolser, we pointed out one of the difficulties encountered in attempting to backfill old tires. It was difficult, even impossible, to easily place and compact granular backfills into a tire casing without using expensive and time-consuming hand labor. Bolser solved this problem by developing a tire cutter which removed a portion of one sidewall of each tire. Sufficient tire was left to provide an acceptable degree of tire casing stiffness and shape, but a large enough "hole' was created for backfilling to be easily accomplished with a small "Bobcat" backhoe. A pictorial view of a "typical" tire is shown in Figure 4.

Next we determined available tire sizes and what backfill materials should be used. Bolser made available tires in a wide variety of sizes, from heavy industrial earthmoving equipment to small automobile tires. It was also critical to create a free-draining system which would not allow any drainage water to seep or flow into the space between the tire wall and the existing basement wall. To accomplish this we chose to backfill the tires with a clean crushed rock material. After limited field trials in a local contractor's yard, we found that for ease of backfilling and creation of a free-draining system, a 1.6 cm (5/8-inch) minus crushed rock was the most economical and practical backfill material. Based on the tire sizes and the backfilled tire weights, we selected two different sizes of tire for this wall, Tractor tires for the lower portion and truck tires for the upper segment. The tire sizes and weights are summarized in Table A, Re-Cycled Tire Data.

Because the specific site backfill materials were undesignated, development of our geotechnical analysis for the rubber tire wall assumed a series of parameters. In our opinion, the parameters are conservative and provided higher-than-typical factors of safety in wall design. Based on our evaluation of the original geotechnical engineer's site data, and our assumptions, we selected the following soil parameters for design purposes:

- Allowable soil bearing pressure in native subgrade soils = 9,765 kg/m^2 * (2,000 psf)
- Active equivalent fluid pressure for walls free to rotate for a distance of 0.001 times the free-standing wall height = 721 kg/m^3 (45 pcf)

■ Coefficient of friction between backfilled tire and crushed rock subgrade surface	=	0.40
■ Maximum estimated vertical settlement	<	2.54 cms (1 inch)
■ Maximum estimated differential settlement over half the length of the wall	<	1.25 cms (1/2 inch)
■ Maximum estimated unit weight of imported backfill soil	=	1,922 kg/m^3 (120 pcf)

* We also allowed for an increase in allowable soil-bearing pressure of one third when considering short-term, transitory seismic loads.

We considered that the rubber tire wall would act as a "mass" retaining wall. To verify this was appropriate, we analyzed the lateral pressures applied to the wall. We used the computer program EPRESS developed by CivilTech of Bellevue (CivilTech, 1995) for this analysis. The program uses The Coulomb Active Earth Pressure theory to develop the weight of the soil wedge, the resultant of the normal and resisting shear forces along the wedge surface, the distributed active force per unit length of wall, and the angle at which this load will be inclined. An iteration was performed for each layer of tires to verify that the applied lateral loads would not cause part, or all, of the completed tire wall to slide, overturn or deform and apply load to the adjacent concrete wall. A depiction of one iteration is presented as Figure 5 for informational purposes.

The computer analysis verified that the proposed tire wall was stable and would resist sliding and overturning under both the applied lateral soil loads as well as the surcharge loads induced by traffic activity on the completed paved surface and from an earthquake. We used the Mononobe/Okabe formula (Seed & Whitman, 1970) to determine the approximate increment of seismically induced lateral load. Assuming that the wall would be free to rotate we estimated that the seismic load increment would be about 208 kg/m^3 (13 pcf) acting over the full wall height.

We were also concerned that the backfilled and completed wall was not subject to any global stability problems. Although the existing concrete basement floor and foundation system were expected to provide adequate resistance to a shear failure under the tire wall and site backfill loads, we felt it necessary to verify the competency of the underlying materials. To accomplish this evaluation we used the SLOPE/W finite element computer program (Geo-Slope International, Version 3, 1995) to evaluate both the static and dynamic stability of the wall and subgrade soil system. To accommodate the "worst case" scenario, we assumed a lateral seismic acceleration value of 0.30g. After 507 iterations we computed an estimated factor of safety of 3.80 for static conditions and 2.43 for dynamic conditions. Both factors of safety are within the ordinarily accepted range so we considered the proposed tire wall to be stable.

Our analyses indicated a wall consisting of two columns of re-cycled rubber tires would be adequate. The lower four rows consisted of tractor-sized tires, while the remainder were of truck tire size. The tires were placed in a staggered pattern to create an essentially solid structure both from front to rear and from top to bottom. A typical detail for the full ten (10) foot high wall is presented in Figure 6.

As mentioned, a major concern was to collect seepage and discharge it under control to avoid the risk of water seeping into the space between the existing concrete wall and the new tire wall. To accomplish this we included a basal drain immediately beneath the wall. This allowed for seepage collection at an elevation below the adjacent wall foundation. It also allowed us to use a coarse, angular, crushed rock material over the drain which generated an increased degree of frictional resistance with the basal row of tires and the crushed rock backfill.

The drain was connected to a new catch basin within the backfill which also collects the surface water from the paved parking lot surface. In turn, the drain connected to the existing storm drain line adjacent to the site at Westlake Avenue North.

One question raised about the use of old tires was related to their potential for ecological and environmental damage. We were fortunate that our research indicated an extensive series of environmental tests had been performed on behalf of the Wisconsin Department of Transportation by Professor Tuncer Edil. His conclusions indicated that automobile tires do not show any likelihood of being a hazardous waste. He also found that when compared to other wastes for which leach test and environmental monitoring data are available, there is apparently little or no likelihood of tires having an adverse effect on groundwater quality given the results of tire leach monitoring.

We were also fortunate that the City of Seattle Department of Construction and Land Use (DCLU), the plans and specification review agency of the City, was receptive to the proposed wall design. We were encouraged by the rapid review and approval by City staff who were intrigued by the idea of re-using "environmentally sensitive" materials for this purpose.

TIRE WALL CONSTRUCTION

At the outset we, and the contractor, were concerned about how to maintain the tires in-place while backfill was "dumped" into the empty tire casings. Review of CALTRANS work (1988) suggested the use of bent steel clips would provide a workable solution. However, as work began, we found that the clips used by CALTRANS were relatively difficult to fabricate and install. Their installation was also time consuming and, therefore, expensive. As a result, we field-bent a clip made of #4 steel reinforcing bar. Our steel clip was essentially a "U" shaped piece of steel bar wide enough to slip over the sides of two adjacent tire casings and hold them together during backfilling. We also found that these clips were essentially non-functional after tire backfilling and compaction was completed. The field constructed clips are depicted in Figure 7.

Another concern related to keeping the backfill within the tire casings. We found when one row of tires was stacked on top of another in staggered fashion backfill materials tended to fall out through the bottom of the tire through the space between the two underlying tires. To prevent this from happening, we used a segment of inexpensive geogrid cut to fit within the bottoms of the tires with intact sidewalls. The backfill forced the geogrid tightly against the tire bead and sidewall thereby preventing the loss of crushed rock backfill. The geogrid layer is shown in Figure 8, and the tire clipping in Figure 9.

After demolition and removal of the old timber deck structure, a trapezoidally-shaped shallow ditch was dug along the full wall alignment. This exposed the firm and competent underlying native soils and allowed for the installation of the basal wall drain. The drain consisted of a 20 cm (8 inch) diameter, perforated, smooth-walled, plastic pipe bedded on, and surrounded by, a clean, free-draining, coarse granular material, which was raised up to the base elevation of the tire wall. As mentioned, this granular material also provided a relatively high frictional resistance to the rock backfilled tires in contact with the drainage material. The drain pipe was installed with sufficient gradient to initiate gravity flow and was connected by tightline to a new storm drain catch basin near the center of the backfilled site. The catch basin discharged into the local storm drain system, thereby removing all the collected water from the site.

Once the drainage system was installed, the basal rows of tires were placed and clipped together. This operation was performed by a three-man crew. One member operated a small Bobcat backhoe to move materials. A second worker moved and placed the tires, while the third member pushed the tires into close contact and clipped them together. It took the crew about one hour to install an approximately 33.5 meter (110 foot) layer of tire wall comprising a double row of tractor tires. The tire installation is depicted in Figure 10.

Once placed and clipped, the basal rows were backfilled with 1.6 cm (5/8-inch) crushed rock. The rock was poured into the open sides of the tires with the Bobcat backhoe and then spread with a hand shovel. When the tires had been filled approximately level with the top sidewall, the backfill was compacted with a vibratory plate compactor. This operation densified the rock backfill and helped achieve the maximum in-place weight of the tire wall. When the first level of the wall had been constructed, the second rows of tires were installed in the same manner, and the backfilling and compaction operation was repeated. After about three rows of tires had been installed, the area behind the tires was backfilled with imported materials, as shown in Figures 11 and 12.

As pointed out earlier, the source materials for this project were a mixture of virtually every soil available in the City of Seattle. In a cost saving decision the client advertised the site as a "free dump" for soil materials from on-going construction sites. This provided an added incentive to some local contractors to quickly deliver backfill materials to the site. Their other choice was to truck excavated soils for several miles out of the City to dispose of them at a regulated and more expensive disposal site. Surprisingly, the source materials were all of generally satisfactory nature.

Basement backfill was placed in lifts of between approximately 20 cms (8 inches) to 30.48 cms (12 inches) in loose thickness. Each lift was compacted with a vibratory steel wheel roller to a maximum of 95 percent of the materials' ASTM D-1557-91 (Modified Proctor) dry density. By use of a vibratory plate compactor within about 1.5 meters (5 feet) of the rear of the tire wall, the contractor was able to avoid imposing any significant lateral load surcharge on the tire wall. As a result, virtually no lateral movement of the tires was observed. Also, as pointed out earlier, the bottoms of the tires forming the upper layers of the wall were covered with pieces of geogrid to prevent backfill materials falling through the spaces between the underlying tires and the tires they supported.

The tire wall construction and backfilling process was continued until the wall and basement backfill reached the design pavement subgrade elevation. The space between the tires and the un-reinforced concrete basement wall was backfilled with polystyrene "peanuts". This provided a compressible filling which would not load the adjacent wall. It also provided a small degree of vertical support for the covering on the gap between the two structures. This gap was covered with a strip of steel flashing. The flashing was epoxy glued to the existing concrete wall and bent to fit against the top of the tire wall backfill.

After the gap was covered, the site was asphalt paved. The 5.08 cm (2 inch) thick asphalt was placed over approximately 10.16 cms (4 inches) of crushed rock base material that was compacted in-place over the finished backfill subgrade. The asphalt was carried out over the edge of the flashing strip to seal it onto the wall backfill. This then presented a relatively clean connection. It also allowed any water from the face of the wall to drain down and onto the asphalt pavement. The pavement surface was sloped to drain to the central catch basin and, thence, to the local storm drain system.

TIRE WALL AND BACKFILL PERFORMANCE

The tire wall has been in-place for approximately three years. The asphalt paved surface has been in daily use as a storage yard and vehicular parking lot. The predominant traffic is by automobiles and light pickup trucks. In addition, the site was also subjected to a magnitude 5.0 earthquake during 1995. No detailed survey of wall cracking inside the original un-reinforced concrete basement has been performed. Several "rough" visual checks (including the use of a graduated rule) of the previously marked cracks found that, to date, no apparent extension or increase of the original cracking. Furthermore, no visible evidence of settlement of, or damage to, the asphalt pavement has been found during regular visual evaluation of the paved surface.

CONCLUSIONS

Based on the design experience, and the comprehensive monitoring of wall construction, we are of the opinion that for locations where aesthetics are not at a premium, such as this "invisible" basement area, a rubber tire wall is one of the most economical structures available. The system also offers the advantage of re-use of an ecologically "difficult" material that is, under normal circumstances, hard to dispose of.

Wall construction only requires a work crew of two men, a small Bobcat type backhoe to excavate and backfill, and a vibratory plate tamper to compact the tire backfill. With an increase in the scale of the backfill behind the wall, it might prove practical to use a larger trackhoe and wheeled compactor in lieu of the above suggested equipment.

The structure can be raised rapidly and provides a sound and competent wall that is capable of resisting substantial lateral loads. This type of wall can, if necessary, also absorb a considerable amount of vertical and lateral movement without undergoing any significant loss of structural integrity. We at CEO are sufficiently impressed with the ease of constructability and economy of the system that we have successfully advocated the use of tire walls on several other projects. These include one where a staged tire wall retains a badly eroded poor quality fill slope. We are encouraged, through our ever-widening experience with tire walls, by their performance and economy and predict that many more such structures will be built in the future.

ACKNOWLEDGEMENT

We at CEO wish to thank those who encouraged the initial concept of re-using re-cycled tires in this innovative manner. In particular, thanks to Al Bolser for his energy and hard work in developing a "useable" old tire that ultimately enabled us, and the contractor, to erect this wall so quickly and economically. We also thank Denny Dochnahl, of Dochnahl Trucking and Excavating, the wall contractor, for his enthusiasm and assistance in making this project work. And, lastly, we would like to thank those at Seattle DCLU for their enthusiastic endorsement of this system.

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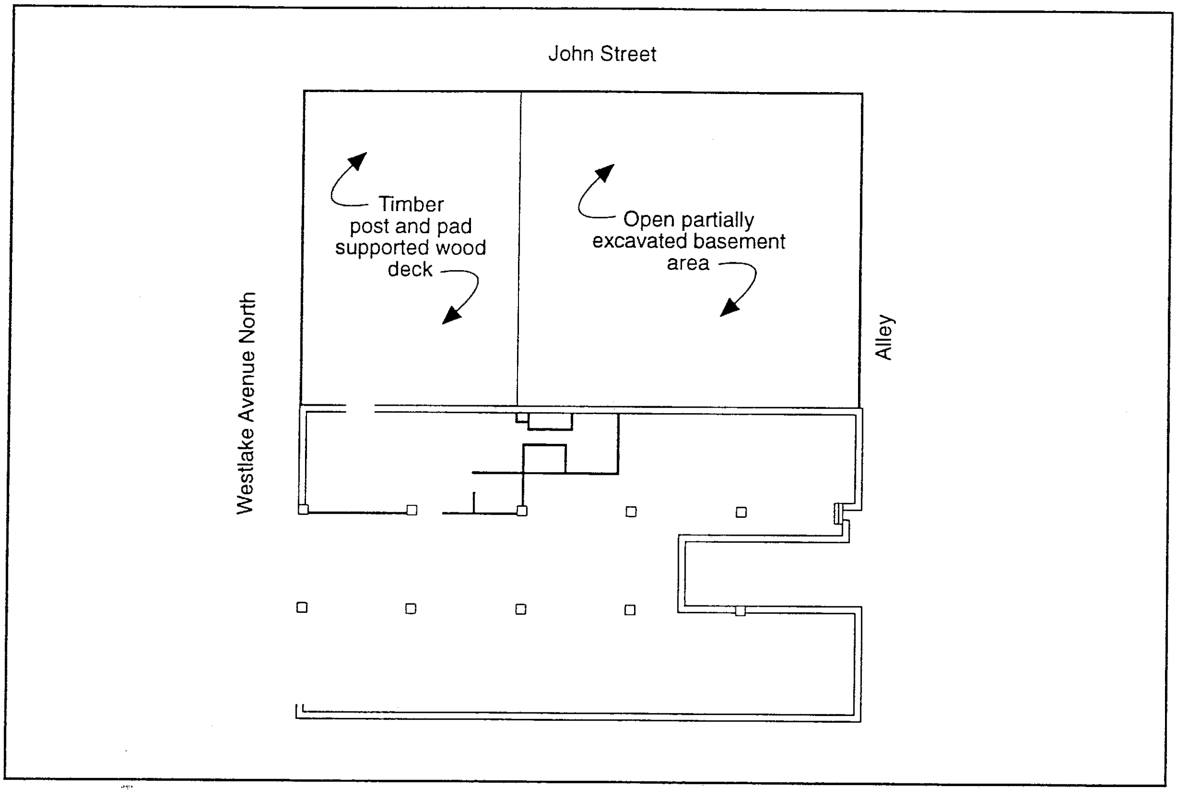


Figure 1: Original site plan

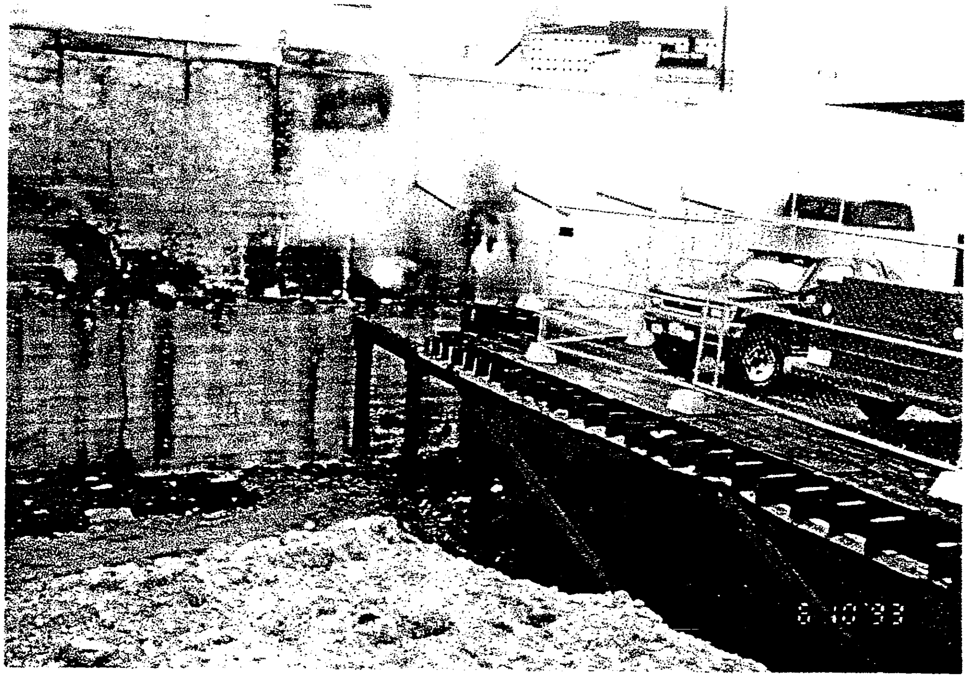


Figure 2: View of site before construction

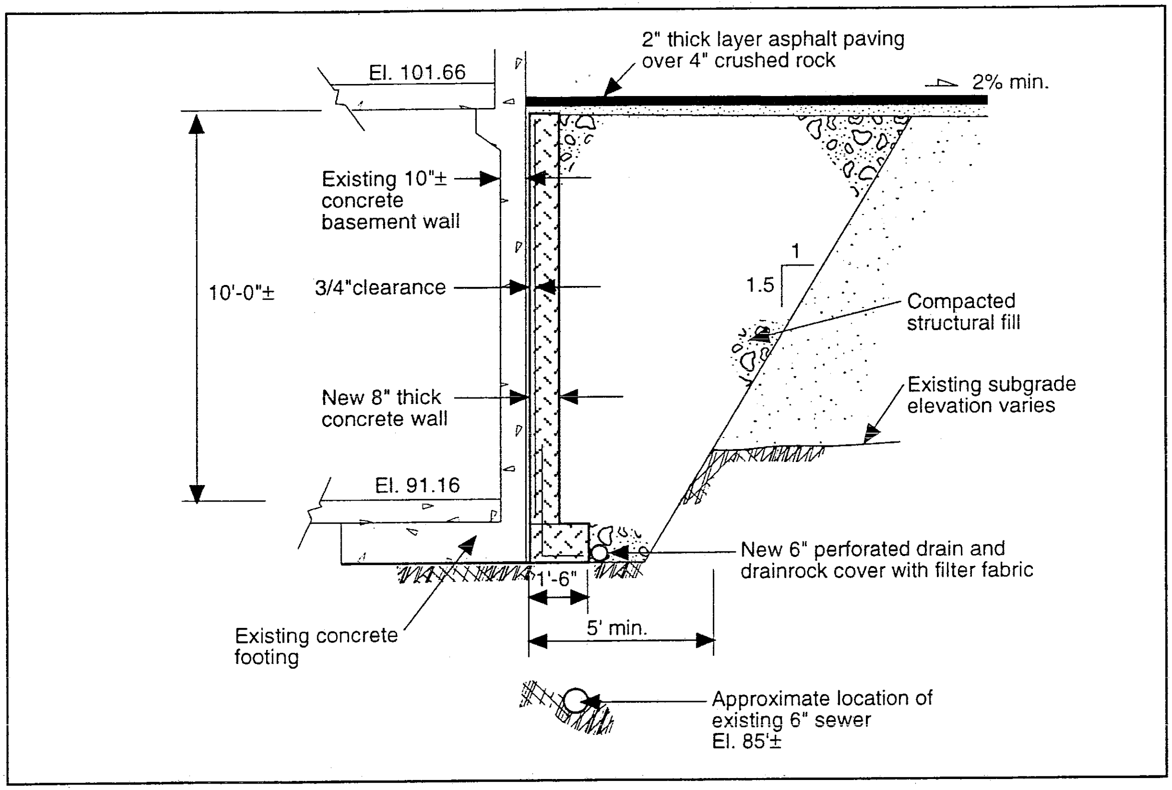


Figure 3: Original wall design detail

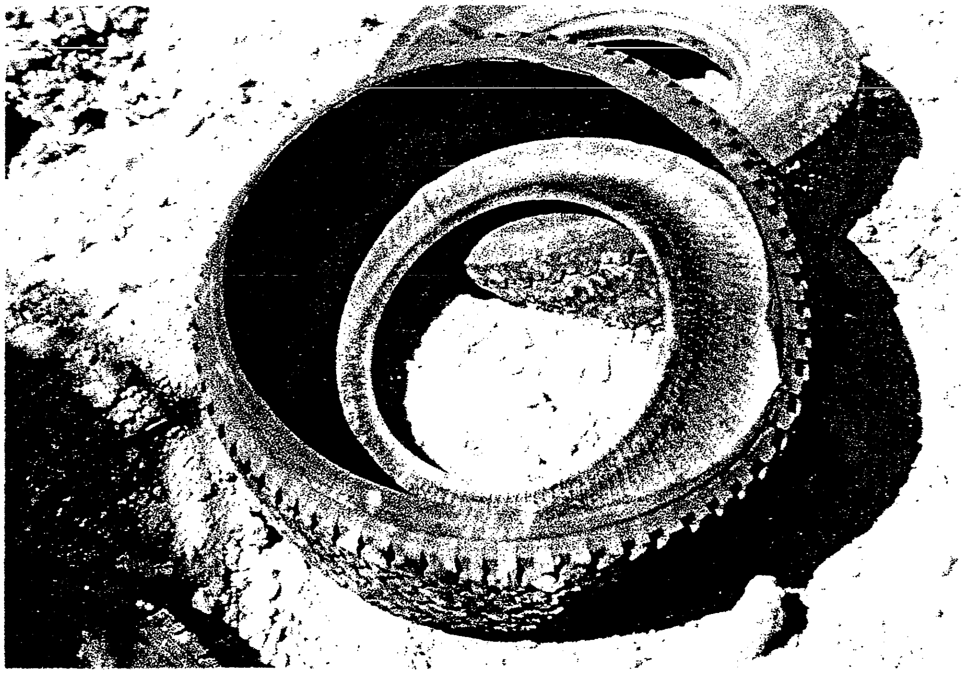
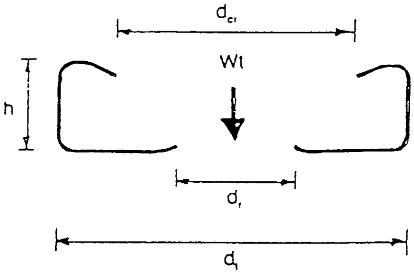


Figure 4: Rubber tire with removed upper sidewall



d_t = Tire Diameter
d_{ct} = Diameter of cut rim
d_r = Diameter of interior rim
h = Width of tire (tread area)
Wt = Weight of tire

TIRE SIZE	DIAMETER OF TIRE	DIAMETER OF CUT RIM	DIAMETER OF INTERIOR RIM	TIRE WIDTH (tread area)	TIRE WEIGHT
(inches)	(inches)	(inches)	(inches)	(inches)	(pounds)
Tractor	114.3 cm (48)	83.82 cm (33)	60.96 cm (24)	40.64 cm (16)	562.5 kg
Truck	109.22 cm (43)	86.36 cm (34)	50.8 cm (20)	30.48 cm (12)	308.5 kg
Automobile	68.58 cm (27)	58.42 cm (23)	35.56 cm (14)	20.32 cm (8)	109 kg

Table A: Re-Cycled Tire Data

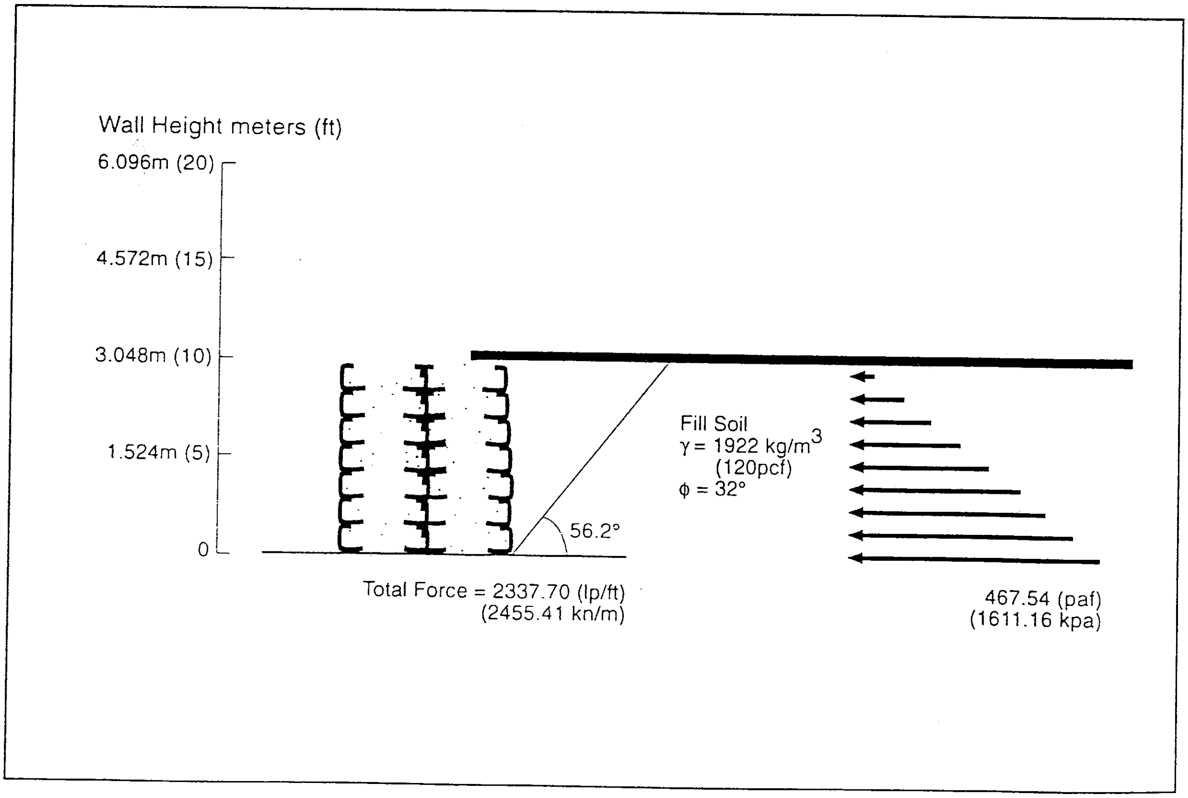


Figure 5: Typical lateral pressure diagram

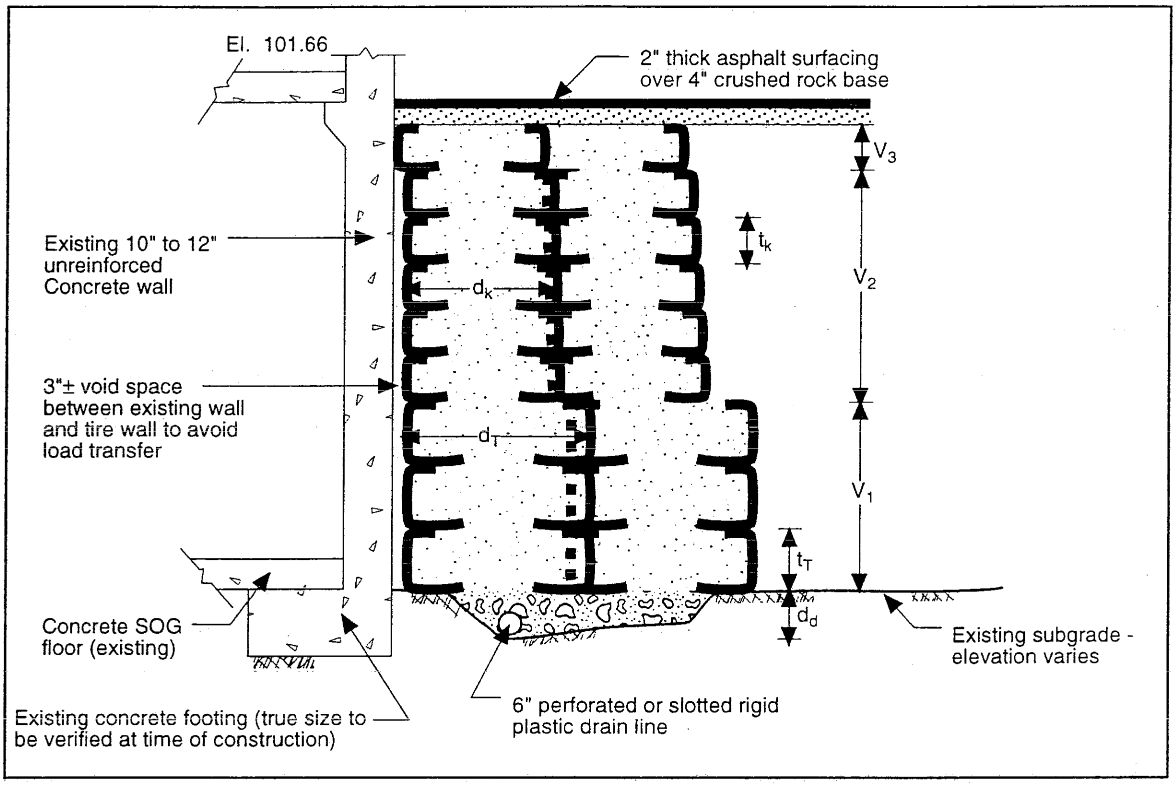


Figure 6: Typical detail of tire wall design

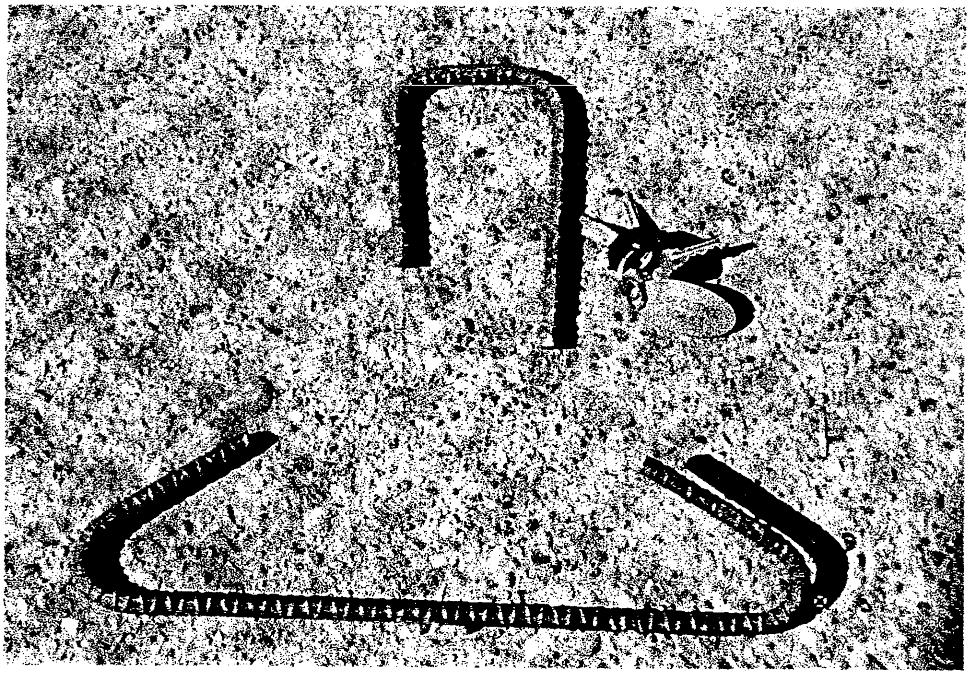


Figure 7: Field constructed tire clips

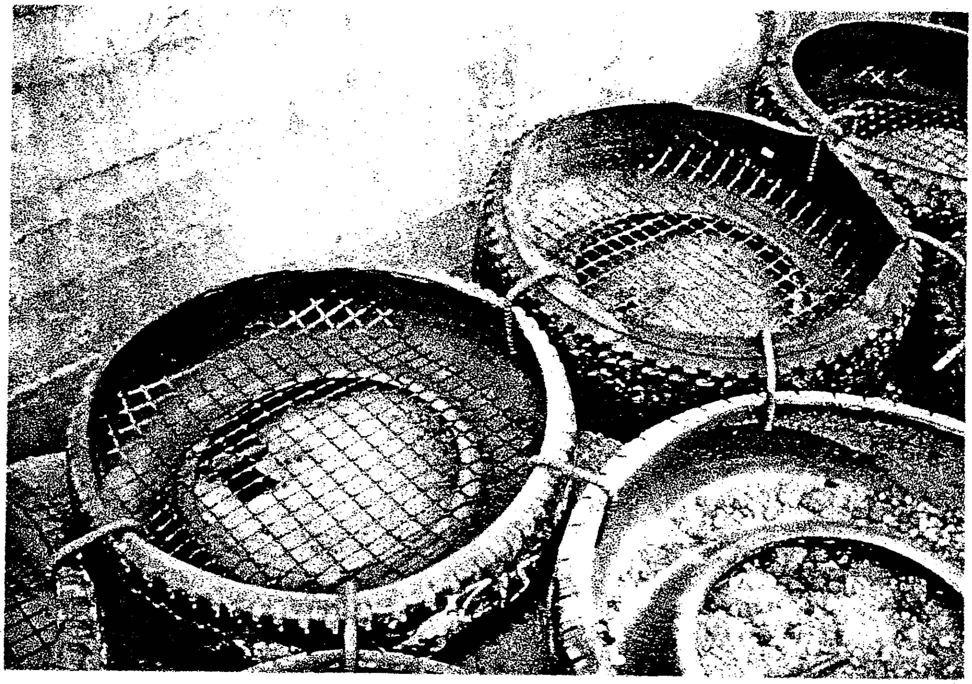


Figure 8: Clipped tires with geogrid inserts

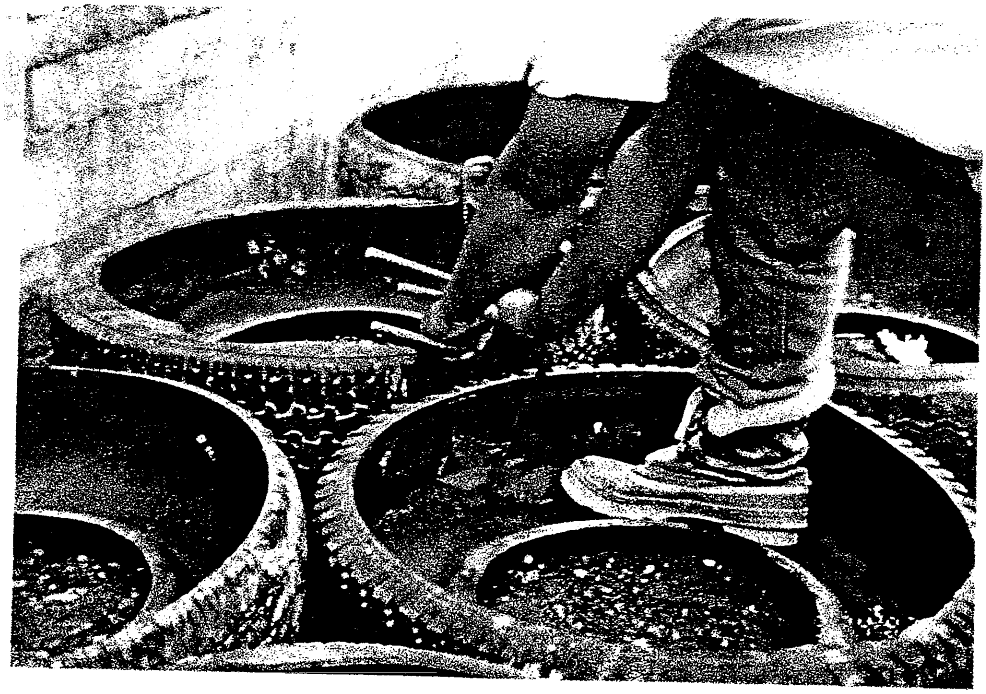


Figure 9: Installed tire clips

Figure 10: Typical tire backfill process

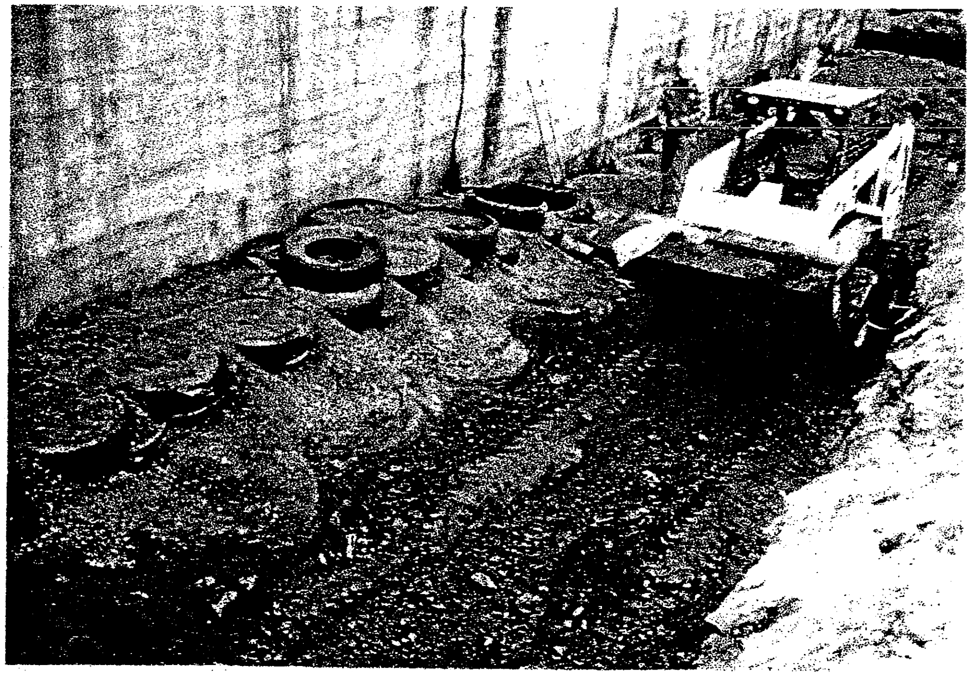


Figure 11: Tire wall and site backfill