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-CONCRETE RECYCLING-

"Why recycle concrete pavements?" There are several reasons. High quality aggregates may be limited in supply, expensive, or not at hand. Transportation costs for bringing in new aggregates as well as for removing old material are also an important factor. Waste disposal is another consideration, especially in major urban reconstruction projects. Hauling and disposing of the material that is removed, if it is not recycled, can have an impact upon the environment. Further, we can definitely say that there are cost savings from recycling.

In 1982 when the Department first decided to recycle portland cement concrete pavements, the contract specifications required that recycling be done. Those projects were carried out from 1983 to 1985, and were set up to get the Michigan construction industry involved in the process and to develop the necessary procedures. Since then, its been optional but the recycling option has been selected by the contractors on every project. In total, the Department has undertaken more than 400 lane miles of concrete pavement recycling, or nearly three million square yards. We estimate at the present time that the savings resulting from recycling are somewhere in the vicinity of three to five dollars per ton of coarse aggregate used. Figure 1 shows the number of square yards that have been done per year from 1983 through 1987. The total project cost for these jobs, including all the other items that were involved, has been about $150 million.

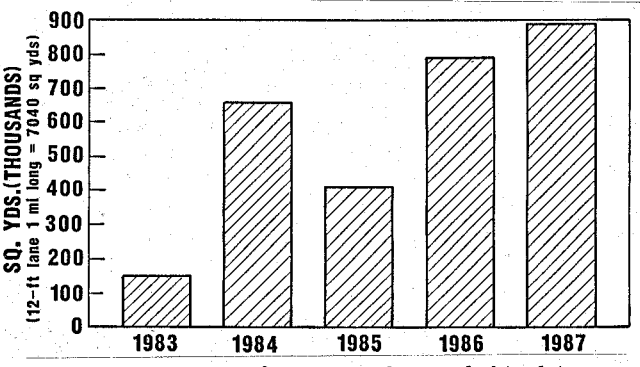

Figure 1. Number of square yards recycled to date.

Breaking The Old Pavement

The recycling procedure starts with the breaking operation. Drop-weight type pavement breakers were used on some areas of the early jobs. Later the contractors used pile driving hammers, supported either on trailer wheels or in an earthmover, and usually rated at about 18,000 ft-lb. Contractors have found that the shape and size of the portion of the shoe that contacts the pavement, has a considerable effect on the way in which the pavement is broken. They also have searched continuously for larger, more effective equipment. Pile hammer pavement breakers used on some recent jobs were rated at approximately 30,000 ft-lb. These machines reduce the surface to rather fine particles in places, but in general the pieces of pavement are relatively large, 2 or 3 ft in size, when removed for hauling to the crusher.

The John Lodge freeway project used a 'guillotine' type breaker. The capacity of this particular machine can be up to 56,000 ft-lb. It has a very heavy steel plate that is repeatedly raised and dropped on its end on the pavement. This machine is capable of delivering the highest energy of any of the machines that have been used, and is an effective pavement breaker.

Another type of breaker that has been used for a few special purpose jobs, is the vibratory, 'sonic,' or resonant breaker. On this machine, a resonance is set up in a beam by a rotating eccentric weight. A shoe attached to the end of the beam rides along the pavement surfacing, striking about 44 blows per second. The machine causes considerably less earth vibration than the drop-hammer types, and although it is a bit slower, it breaks the pavement into smaller pieces and effectively separates the steel from the concrete.

Pavement Removal and Processing

Once the pavement has been cracked, it is removed from the grade and transported to the crusher. Some contractors use a backhoe with an attachment at the end called a 'rhino horn,' which is used as a ripper to separate the pavement pieces and windrow them on the grade. This ripper removes some steel on the grade and breaks the rest into small enough pieces to be handled at the crusher. It also gets the pavement ready to load with end-loaders. Other contractors have chosen to load with backhoes directly off the grade without using a ripper tooth.

If a project doesn't have select gravel base materials underneath the concrete (such as the John Lodge freeway job which was set directly on sand) we needn't be as concerned about picking up and incorporating gravel particles that may not be of the type or durability that one would want to reincorporate into a new pavement mix. There are considerable differences in the amounts of base materials and fines that are picked up by contractor operations. This also is somewhat variable depending on whether the grade is wet or dry. Care must be taken in removing the pavement, as once unwanted materials are incorporated into the salvage pile, it becomes very difficult, and in some cases practically impossible, to separate these materials; especially if there is clay involved. Fine granular material can usually be screened away. 'Grizzlies' or screens directly below the primary crusher have been used to allow finer materials to pass through and separate from the coarser material that comes out of the crusher.

A primary concern is that materials are not picked up on the grade or at the crusher site that should not be incorporated in the mix. Construction sites on clay grade are troublesome. The hauling and stockpiling operation can incorporate clay into the salvaged concrete pile, and the reclaiming operation from the salvage pile to feed the crusher can pick up still more. This should be an area of concern at the pickup site on the grade as well as at the plant site or crusher site. Once clay balls are mixed with the aggregate

there is no reasonable way to get them back out. Clay balls quickly generate localized failures if placed in the finished concrete.

Early jobs were done with jaw type primary crushers with secondary, sometimes tertiary roller crushers. Contractors found that with adequate separation of the steel reinforcement on the grade, and breaking it up into relatively small pieces to be fed through the crusher, most of the steel could be removed by electromagnets over the belts. In many cases, contractors used a person as a 'picker' to remove pieces left over on the feed belts. A second type of crusher that has been used very effectively is the impact type crusher, which has been used on quite a few jobs. It does seem to generate a bit more fine material than a jaw crusher, but production is high and it is quite effective in handling relatively large pieces of steel.

On early jobs the steel was so contaminated with adhering particles of concrete that it was not usable as salvage steel, and was buried rather than recycled as scrap. On some of the later jobs, and on the job where the vibratory breaker was used, the steel has come out very clean and probably of sufficient quality to be used as scrap steel.

Fine Aggregate

Let us look at the products of the crushing operation; first, the fine aggregate that results. One thing that should be considered carefully is the amount of contamination allowed in the material picked from the grade. Next, its treatment in the removal, stockpiling, reclaiming, and crushing operation, as this relates to the intended end use of the fine portion aggregate, and in the decision of whether or not it is intended to use the recycled fine aggregate in the mix. Recycled concrete mixes can be made, and have been made, containing relatively significant amounts of recycled fines, as well as recycled coarse aggregate. However, when recycled fines are used, since these materials are angular and more porous and absorptive than natural sand, they add a harshness to the mix and make it somewhat more difficult to handle and consolidate.

We have found that recycled fines are not suitable for use in drainage layers beneath the pavement. The cementitious materials that are attached to the surfaces of the fines tend to form a solution when water percolates through them. This solution causes precipitates to form in the drainage structure or on the geotextile fabric that is used to wrap the drain, and this can plug the drain. Therefore, we no longer allow the use of recycled fine materials in drainage layers of the pavement base.

Another consideration is the amount of salt in the concrete that is being recycled, much of which will be on the surfaces of the fine aggregate particles. This should be considered before deciding whether or not to use the recycled fines. Yet another factor is the amount of fine dirt that has been incorporated in the recycled aggregate. The finer materials or dirt end up in the fine aggregate pile contaminating it with excess fines which generally cause a decrease in strength of the concrete. In general, we have found that the more recycled fines used in the mix, the lower the average strength of the concrete; therefore, recycled fines have been prohibited on recent MDOT projects.

Coarse Aggregate

The major portion of recycled material used in Michigan is the coarse aggregate, and there are several considerations concerning its suitability for use in new concrete. From a design point of view, one should consider the amount of deleterious materials that are in the old pavement. For instance, if a serious problem with joint deterioration and popouts due to soft stone or chert existed in the original pavement, it might not be advisable to recycle it. On the other hand, if the old pavement contains a D-cracking aggregate, the durability of that aggregate is improved somewhat by the crushing operation since particle size is reduced and the long-term weathering in-place has already taken its toll on some of those aggregates that would have deteriorated in the recycled concrete. However, moderate improvement of a very low quality material may not result in an aggregate that is suitable for a modern high-capacity highway. Recent tests, before and after recycling of relatively low quality aggregates on the Interstate, showed very little difference in performance.

While relatively low quality aggregates are beneficiated by the recycling process, very high quality aggregates may be degraded somewhat. Recycled aggregate is more porous and absorptive than original aggregate and one must beware of contamination. Again, care should be taken to avoid inclusion of clay balls, bituminous patching materials, joint seals, expansion joint fillers, and tramp steel; any one of which can give problems in the finished pavement. Recycling provides more material than is needed for a new pavement of the same width and thickness. For instance, if a 9-in. pavement is crushed, there is about enough coarse aggregate available to pave a new 10-in. pavement with concrete shoulders on both sides.

Recycled Mixes

Batching presents no major problems, though preliminary planning and evaluation of this operation is suggested. Questions must be addressed such as: are the recycled fines to be used? Does the mix design require additives such as water reducers? Fly ash is useful in improving consolidation, and also increases durability. Keep in mind that while ordinary concretes gain significant strength with reduced water/cement ratio, recycled mixes—expecially those with recycled fines—tend to decrease in strength at very low water/cement ratios. This may be due at least in part to the more difficult job of consolidation when these harsher mixes are used. Another factor to note is that the modulus of elasticity is reduced when recycled materials are used and the amount of absorption is generally increased over native materials. It is suggested that specifications for recycling jobs include specific items of planning by the contractor and agreement by the owner, on the methods used for pickup, stockpiling, reclaiming, crushing, and batching to avoid contamination.

Paving is relatively straightforward, although there is somewhat more harshness to the mix, expecially if recycled fines are used. Extra attention should be given to the paver, as most of them were not designed to deal with these harsher mixes, and do not seem to consolidate them as well. This is an item that should be attended to; it is related to the condition, number, and function of the vibrators. Adjustment can be made on many of the newer pavers with hydraulic vibrators, that would be useful in assuring better consolidation of the concrete. Excellent ride quality can be achieved on recycled pavements. The contractor on the John Lodge freeway project produced the best ride quality ever attained on a new concrete project, in Michigan.

Remarks

It is evident that the roadbuilding industry is willing and able to recycle concrete pavements. Reuse of the material removed from the project is especially desirable in confined urban environments. Technology is available to produce clean aggregates of acceptable quality. Evaluation of the suitability of the existing material must be made prior to setting up a recycling job. Quality control and quality assurance are extremely important to the attainment of a durable pavement with good riding quality.

It is especially interesting to participate in a process that turns an environmentally undesirable waste product into the raw material for new construction. Additional efforts are warranted to see that the salvaged steel reinforcement also is recyclable in the steel industry.

-Chuck Arnold

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