

Rubblizing Concrete Pavements Using Resonant Vibration Technology

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Abstract

The paper presents an engineering and technical description of the technology known as pavement concrete rubblizing, which is used for both, concrete pavement rehabilitation and as a demolition method for concrete recycling. The paper presents the results of the first Chilean experience with rubblizing and demolition and recycling. Pavement rubblizing may be defined as a technique that fractures the concrete slab into angular interlocked pieces using a "resonant vibration" machine. Once concrete pavement has been rubblized, an overlay is built on top of the fractured material. This paper also includes a summary of: engineering principles of the dynamic process for concrete Rubblizing and criterion used for structural design and summary of the construction process.

Keywords

Rubblizing, recycling, pavement, concrete, demolition.

INTRODUCTION

Around the world and particularly in Chile there are a large number of concrete pavements located in: urban and interurban highways, airports, ports and industrial sites. All pavements suffer a progressive distress, produced by transit loads and climate (temperature, rain, humidity). Pavement durability will depend mainly on: the quality of the original engineering project, the construction quality and the maintenance strategy carried out during the design period.

Several techniques allow extending pavement life. These techniques may be classified in two categories: maintenance and rehabilitation [Thenoux, 2003a]. Maintenance techniques improve pavement functional capacity and help to extend pavement structural life while habilitation techniques increase or replace pavement structural capacity, recovering the structural condition. Pavement maintenance must be carried out in an early stage of pavement deterioration, and generally rehabilitation is normally applied when pavement structure is in poor or terminal condition.

The most common rehabilitation techniques used in rigid pavements within Chilean national road network consists in both, direct asphalt overlays or granular material overlays plus an asphalt layer on top. In general, asphalt overlays are more cost-effective compared to concrete overlays [NAPA, 1995]. Asphalt overlays improve functional pavement condition and increase structural capacity; however most overlay technique will show reflective cracking within a relative short period of time (may start

the first year of service). Although, most concrete fracturing slab techniques have demonstrated to be effective, delaying or avoiding crack reflection, distress models of rehabilitated sections through slab fracturing methods have demonstrated that best long term behavior is achieved when using rubblizing technique with a resonant breaker [NAPA, 1995].

CONCRETE PAVEMENT REHABILITATION

In many aspects, pavement rehabilitation is more complex than a new pavement design. A suitable rehabilitation policy should aim to extend structural design period of an existing pavement, but also to reduce investment costs. Several rehabilitation methods of concrete pavements are available. These are : Do nothing, slab replacement, hot mix asphalt (HMA) overlays, portland cement concrete (PCC) overlays and reconstruction [NAPA, 1995].

It is feasible to build overlays using either concrete or asphalt material. Nevertheless, asphalt is generally more economical and technically accepted, particularly if transit time delay costs are incorporated into life cycle cost analysis [NAPA, 1995]. HMA overlays will restore ride-ability, improve long-term functional pavement performance as well as increase the structural capacity of the existing pavement in a most economical manner. However, one of the most significant design problems of this type of rehabilitation is the potential to develop reflection cracking distress through the HMA overlay. This phenomenon may eventually cause a serious loss in performance and service life of the HMA overlay.

Reflection cracking of HMA overlays

A simple way to explain the crack reflection mechanism is the following: when asphalt overlay is placed on top of a deteriorated concrete pavement, pavement joints or cracks will induce stresses originated from temperature gradients and/or transit loads. The horizontal and vertical movements induce tension and shear forces. This complex combination of both tensile stresses and shear stresses at the interface of the HMA overlay will eventually cause the development of cracks across the entire thickness of the HMA overlay. To prevent or delay reflection cracking, fracture slab technique offers one of the most economical and successful ways to eliminate reflection cracking of HMA overlay placed on existing PCC pavements [NAPA, 1995].

Fracture slab techniques

Fracture slab techniques have been used extensively in United States during the last 20 years, supported by different agencies: AASHTO (American Association of State Highway and Transportation Officials), NAPA (National Asphalt Pavement Association) and Asphalt Institute. The major categories of these techniques are:

- **Crack and Seat (or Break and Seat):** The objective of the Crack and Seat technique is to reduce reflection cracking in the HMA overlay by reducing the effective slab length of the PCC pavement. The cracking process requires high energy which is obtained through a big load and high amplitude. Seating of the broken slabs after cracking is intended to re-establish the support between the base or subbase and the fracture PCC slab.
- **Rubblization:** The objective of the Rubblization fracture slab technique is to eliminate reflection cracking in the HMA overlay by the complete destruction of the existing slab action of the PCC

pavement. Resonant Rubblization also de-bonds all reinforcing steel in the slab. This technique is applicable to all types of existing PCC pavements.

RUBBLIZING USING A RESONANT BREAKER

The rubblizing process using a resonant breaker is defined as a fast fracturing process, where a machine breaks the pavement into small interlocked pieces. The principle of the machine is a massive steel beam, which vibrates through a frequency close to resonance. The vibratory motion is transmitted to a hammer that is moved along the pavement surface in front of the machine (Figure 1-(a)).

The rubblizing fracturing pattern and hammer is shown in Figure 1-(b). The final rubblized product is a high modulus granular base layer, achieving a relatively high structural capacity with an excellent performance. One of the most remarkable properties of the technique is that does not affect the underlying base and sub-grade materials due to the very low amplitude in which the resonant load is applied: vibration energy is entirely absorbed by concrete [Resonant Machines, 2005]. The machine allows setting the beam dynamic parameters (amplitude and frequency). Through a microprocessor the machine controls particle size of the fractured slab optimizing the rubblized material properties.

The resonant beam is the most important component of the machine, since it is the device that transmits the energy to the concrete slab. Vibration is induced on the beam by the hydraulically driven eccentric weights, which convert circular motion into vibratory motion of one mode. Generally, the beam works in amplitudes between 125 to 250 mm and frequencies between 42 and 46 Hertz. Once the vibration hammer starts to work at the optimal frequency and amplitude, rubblizing a concrete slab may be achieved at a rate of 700 square meters per hour [Thenoux *et al.*, 2004a].

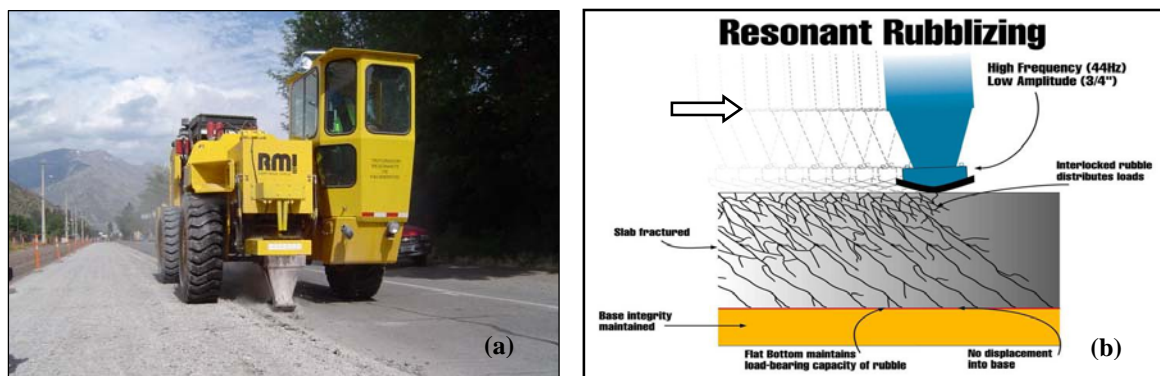


Figure 1: Rubblizing technique at 60-CH Highway Chile (a) and concrete pattern fracture (b)

Technology advantages

The rubblizing presents different advantages from technical, economical, environmental and operational point of views. These are:

- **Technical:** The rubblizing technique is a construction method similar to a reconstruction since all failure pattern of the existing pavement are destroyed (cracking, spalling, pumping, rough riding, lost of bonding, raveling, faulting, etc.) producing a new base material. The new base material will have a

structural capacity in excess of a good asphalt base layer. Pavement research programs at USA have followed different concrete fractured pavement projects with an asphalt layer on the surface during its operational life. Measured through PCI (Pavement Condition Index), rubblized pavements have reached the best performance [NAPA, 1995]. From the structural point of view the subgrade is not affected by the rubblized process and reflecting cracking is completely eliminated.

- **Economical:** Important cost differences exist between rubblizing and traditional reconstruction or rehabilitation techniques. A comparative analysis was made at Arkansas, USA. In this study, the total reconstruction cost was 3 to 4 times greater than the rubblizing alternatives [Asphalt Institute, 2001]. Other States have done the same analysis and the rate reconstruction/rubblizing is about 3:1 to 4:1 [Resonant Machines, 2005]. One of the main factors that reduce rubblizing cost is the efficiency and effectiveness of the process and the high performance of the machine (700 m²/hour or 1.5 km on a single lane per day).
- **Environmental:** This technique can be considered as a pavement recycling method since is possible to reutilize the rubblized material in-situ. Recycling pavement materials generate the following environmental advantages [Thenoux *et al.*, 2003b]: Reduces haulage and new material volumes from borrow pits, reduces haulage of waste concrete, reduces pollution associated to construction and demolition processes (dust, smoke, noise), reduces driver's user impact and cost during the construction, construction time is shorter compared to other rehabilitation techniques, reduces energy consumption and emissions, etc.
- **Operational advantages for pavement demolition:** Rubblizing technology can be applied in rehabilitation as well as in pavement demolition projects. Compared to traditional demolition techniques, is possible to identify several advantages: Rubblized concrete material swells only 20-30%, reducing transportation volumes compared to high impact broken concrete which swells more than 100%, the rubblizing material has a smaller particle size, thus the material may be easily recycle in plant, the demolition process does not affect adjacent structures, etc.

CRITERIA AND METHODS FOR STRUCTURAL DESIGN

The structural design method for rubblized pavement is supported by the following guidelines: Structural Design Guide, AASHTO [AASHTO, 1993], Manual Series, Asphalt Institute (MS-17) [Asphalt Institute, 1995]. and Information Series, NAPA (IS-117) [NAPA, 1995]. The most accepted structural design method is AASHTO, which uses Structural Numbers and where the basic design equation is:

$$SN_{ol} = a_{ol} * D_{ol} = SN_f - SN_{eff} \quad (\text{Ecuación 1})$$

Where : SN_{ol} = Requerid overlay structural number.

a_{ol} = Structural coefficient for the asphalt concrete overlay.

D_{ol} = Requerid overlay thickness.

SN_f = Structural number requerid to carry future traffic.

SN_{eff} = Effective structural number of the existing pavement after fracturing.

Determine the overlay thickness is a simple procedure, but is necessary to know the material structural coefficients. AASHTO recommend the structural coefficient between 0.14 to 0.3 [AASHTO, 1993]. Recommended structural coefficients by NAPA are showed in Table 1 [NAPA, 1995].

Table 1: Structural coefficients used for rubblizing material

Reliability (%)	a_2
75	0,34
85	0,30
90	0,29
95	0,26
99	0,20

FIRST CHILEAN EXPERIENCE WHITH RUBBLIZING

The first application in Chile was done late in year 2004. A 300 m, test section was constructed in the main Chilean international highway which connects Chile and Argentina through the Andes mountain. This, road may be considered as the most heavily traffic road in Chile.

Figure 3-(a), shows typical original conditions of the concrete existing concrete pavement. The test section was located between a relative large construction project (aprox. 50 km) where part of the project was reconstructed and an important part was being rehabilitated using a granular base overlay plus asphalt overlay (Figure 3-(b)). This technique is widely used in for highway concrete pavement rehabilitation in Chile. Although, direct asphalt overlay was also considered this is not included in the analysis, since due to the actual pavement conditions and traffic there is a high potential for reflecting cracking.



Figure 3: typical pavement original conditions (a) and overlay with granular base (b)

The test section was selected from a segment that according to the engineering project was going to be overlay (with granular base plus asphalt overlay), so us to compared performance and rehabilitation costs. Figure 4, shows the two rehabilitation alternatives to be compared.

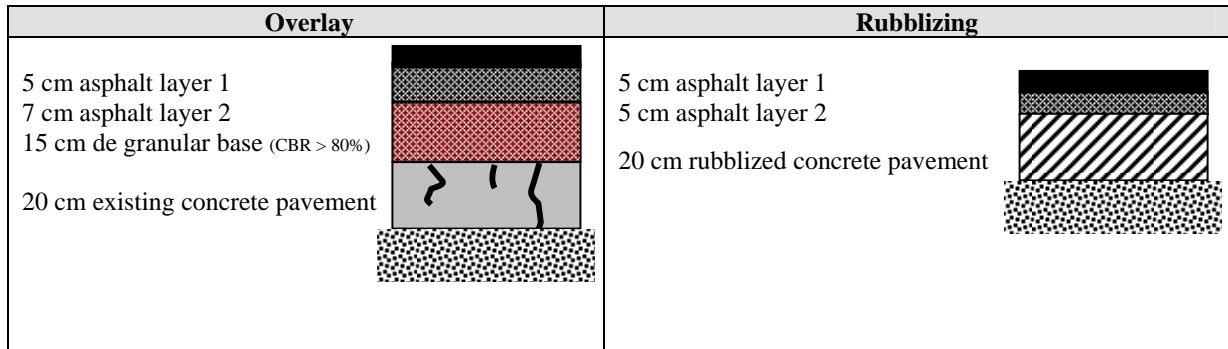


Figure 4: Rehabilitation alternatives

Comparisons

The first analysis was done by evaluating total construction time for a similar length of road. Considering only those periods of time which were strictly related to the construction process it took less than three days for the rubblizing alternative and seven days for overlaying. Also, reconstruction was evaluated but they were so many other problems that a reconstruction section of the same length extended for more than three weeks.

A second analysis was a direct cost analysis for different alternatives using actual costs and reference [Thenoux, 2004b]. Rubblizing, has the least cost compare to overlaying and reconstruction.

Table 2: Estimated direct costs

Alternative	Cost (US\$/km)	Relation
Reconstruction	161.875	2,1
Overlaying	123.253	1,6
Rubblizing	78.796	1,0

The third analysis that was planned to do, was to study and compared performance. Unfortunately ones the road was given to the traffic a heavy spring rain was experimented for three continuously days. Drainage design was very poor so many sections of the road where completely soaked for this extended time while heavy traffic was going through.

Figure 5-(a) and Figure 5-(b), shows how the road looks after the rain. Although was not possible to do traffic performance analysis it was possible to prove drainage performance of the rubblized layer is excellent.

The road was damage almost in all its extension. Since drainage was very poor water did not drain out from the granular overlay. It could not drain laterally fast enough due to the lack of lateral drainage and it could not drain downwards due to the existing concrete pavement. The section that was Rubblized being located under the same conditions performed very well. The rubblized layer is not water susceptible and it drains laterally very easy, thus going good performance of the asphalt overlay layer.



Figure 5: Rubblized section (a) end overlay section (b) after the rain

The last analysis that was done was a sieve analysis of the upper part of the rubblized material. This is composed approximately with 15 % sand and 85% medium coarse size. The sieve analysis for each size is shown in Figure 6. Based on this results this material may be used directly in other applications without further crushing.

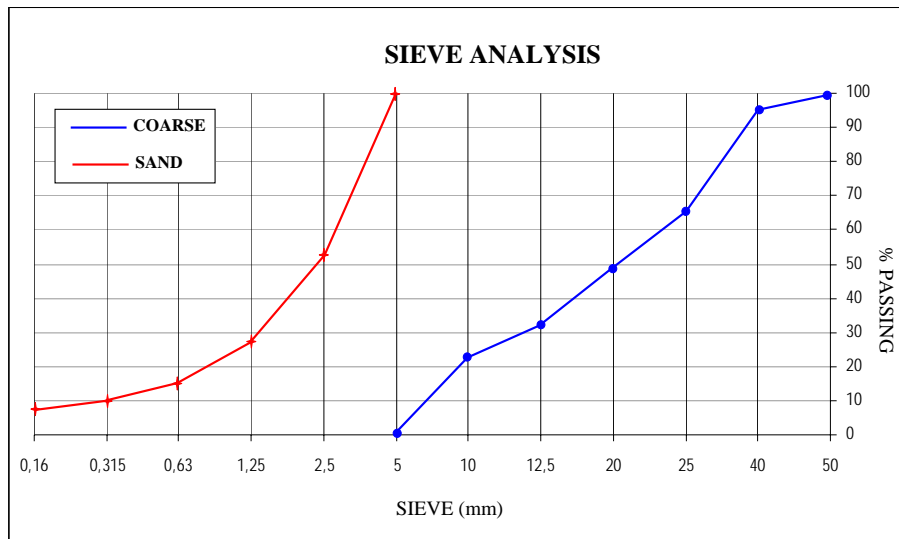


Figure 6: Sieve analysis of rubblized material

CONCLUSIONS

According to the information presented above, rubblizing is a feasible technique from the technical, environmental and operational point of view. The technology reduces environmental impact, haulage distances and energy consumption. Is relatively fast and provides high confidence on the properties of the final product. The technique fractures distressed concrete, destroying all failure patterns and does

not affect the underlying granular layers (subbase and sub-grade), nor does it effect underground utilities. The final product is a high modulus base, suitable for an asphalt overlay.

Rubblizing has been widely accepted in United States. The technique is recommended by known technical institutions as Asphalt Institute, NAPA and AASHTO. Further, structural design methods are available from guidelines written by these institutions.

The test section performed in Chile, was subjected to an inspected rainfall but in turns it was possible to prove the effectiveness of the rubblized technique and the good drainage properties of the rubblized material. Although was not possible to compare the test section traffic performance with the overlay alternative, at this time after 5 month of service the rubblized section is outperforming. Cost and construction time was compared and it was proven that rubblized will offer greater economic advantages and construction time reduction.

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