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Application of rubblizing technology in the recycling of road and airfield pavements

Abstract: Modern road and airfield pavement construction increasingly incorporates recycled materials as akey component of sustainable development. The use of reclaimed materials not only reduces the negative environmental impact—by lowering the consumption of natural resources and carbon dioxide emissions—but also contributes to reducing investment costs. One of the effective recycling methods in road and airfield pavement engineering is the rubblization technique. This process involves fracturing (breaking) existing Portland cement concrete pavements using one of the available methods, such as the Resonant Pavement Breaker (RMI), Multi-Head Breaker (MHB), or Guillotine Pavement Breaker (GPB), and subsequently reusing the resulting crushed concrete as a base layer in road and airfield pavement rehabilitation projects. The article presents examples of rubblization applications as well as the effects of using recycled concrete aggregate in the rehabilitation of road and airfield pavements. Rubblizing is an example of a sustainable practice in infrastructure construction, which not only contributes to the protection of the natural environment but can also be regarded as a form of recycling of concrete pavement from roads and airfields. The research results presented in the paper clearly confirm the positive impact of rubblizing in the technical aspect of carrying out works related to the rehabilitation (reconstruction) of existing road and airfield pavements.

Keywords: concrete pavement, recycling, roads and airports, rubblizing, subbase.

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1. INTRODUCTION

Rubblizing technology, defined as the fracturing and breaking of existing concrete pavements [1], was developed in the state of Wisconsin (USA) in the early 1980s [2]. Its purpose was to obtain a structurally strong base layer prior to the placement of an additional pavement course using asphalt overlays [3]. This method prevents the occurrence of reflective cracking in the overlay layers by densifying and leveling existing defects and joints in the concrete pavement. The in-situ fractured layer consists of irregularly sized and shaped concrete fragments which, after being seated and compacted into the subgrade, form a dense, interlocked layer. This layer exhibits high shear strength and resistance to rutting [3].

Rubblizing technology enables a significant reduction in the duration of road and airfield construction works, thereby lowering investment costs [4]. Its application is also associated with environmental benefits, as the existing concrete pavement is reused. The resulting crushed material serves as a base layer, eliminating the need for additional natural aggregates. Consequently, waste generation is minimized and the scope of transport operations – both for waste removal and delivery of new materials – is reduced.

Rubblizing represents an example of sustainable practice in infrastructure engineering, contributing to environmental protection and serving as a recycling method for road and airfield concrete pavements. The technology was first implemented in Poland in 2009 during the reconstruction of National Road No. 22 between Chojnice and Tczew (the so-called Berlinka) [5].

In 2016, rubblizing was applied on Voivodeship Road No. 801 (Warszawa-Puławy, the so-called Nadwiślanka) near Wilga, where the 60-year-old concrete pavement was fractured using a specialized self-propelled Multi-Head Breaker (MHB T8600) [6]. Another example is the reconstruction of Voivodeship Road No. 142 on the Szczecin-Łęczyca section, with a total length of 21.8 km [2]. At present, rubblizing technology is applied on both civilian and military airfields. The first airports where this method was employed included Kraków Balice International Airport, Rzeszów Jasionka Airport, Olsztyn Mazury Airport, and Bydgoszcz Airport.

In the analyzed cases, the fractured concrete pavement obtained through rubblizing was utilized as a base layer within the pavement construction. The reuse of this material in situ allowed for a reduction in the demand for natural aggregates, a decrease in transport costs, and a minimization of waste generated during construction.

It should be noted that, in the case of road pavements, the requirements for the structural layer formed as a result of rubblizing are specified in the "Guidelines for the Use of Recycled Concrete Pavement Materials" [7]. About airfield pavements, such requirements were included only in 2025 in the revised defense standard concerning Portland cement concrete airfield pavements [8].

This article presents the results of tests carried out on two airfield facilities in Poland where two different rubblizing methods were applied.

2. RUBBLIZING TECHNOLOGY AND METHODS

2.1. MULTI-HEAD BREAKER METHOD (MHB)

The Multi-Head Breaker is a self-propelled wheeled unit equipped with multiple hammer pairs (Fig. 1).

Fig. 1. A self-propelled wheeled MHB [9]

In the MHB system, half of the hammers are arranged in the front row, while the remaining half are located in the rear row, which is diagonally offset relative to the front row. Each pair of hammers is connected to an individual hydraulic cylinder, functioning as an independent unit that generates variable impact energy regardless of the selected drop height and operating frequency (30-35 blows per minute). The machine, with a base working width of 2.44 m, is equipped with 12 hammers, each 200 mm wide [3]. Two additional side wings are mounted to the machine frame, each fitted with two hammers of 300-381 mm width, resulting in a total operating width of 3.95 m. During operation, the operator can continuously adjust both the machine's travel speed and the drop height of each hammer, enabling optimization of the pavement fragmentation process. Individual hammers can be deactivated at any moment, which ensures the protection of underground utilities. The hydraulic control system provides the operator with complete command over the machine. The intended result is a uniformly fractured concrete surface, with particle size not exceeding 310 mm in diameter. Moreover, at least 75% of the aggregate should comply with the following dimensional limits:

- in the lower half of the slab – 230 mm,
- in the upper half of the slab – 75 mm,
- at the slab surface – 50 mm [3].

A major advantage of the MHB system is that the fractured material remains directly behind the machine, unlike in other methods where the debris is displaced laterally. As a consequence, the relaxed and fragmented pavement is not compacted by subsequent traffic, which is of particular significance in the case of weak subgrade soils, where this effect directly contributes to the load-bearing capacity of the rehabilitated pavement [10].

2.2. GUILLOTINE PAVEMENT BREAKER (GPB) METHOD

The self-propelled Guillotine Pavement Breaker (Fig. 2) is designed for the cracking and stress relief of concrete pavements on roads, highways, and airfields. The machine can also process concrete pavements covered with an asphalt wearing course, applied for technical or safety reasons. The operating principle ensures that the concrete is fractured without generating sharp fragments or secondary cracking of the new surface. During the process, the concrete layer is completely broken. The resulting fragments can either be collected using conventional loaders or reused directly, after supplementary compaction with a roller, as a stable base layer for subsequent pavement courses [9].

The GPB enables stepless adjustment of feed rate and drop height, which guarantees continuous operation. The weight is raised by a mechanical winch driven by a jaw clutch and released from any selected height. The impact force depends on the lifting height, while spacing and fragment size are determined by the adjustable feed movement.

Fig. 2. The self-propelled concrete guillotine GPB [9]

The guillotine can fracture concrete uniformly into particles not exceeding 310 mm. Depending on slab thickness (up to 30 cm) and the number of passes, the particle size can be further reduced.

2.3. ULTRASONIC METHOD (RMI)

The RMI ultrasonic method applies acoustic waves that induce forced vibrations within the concrete structure, resulting in pavement fragmentation. By adjusting the wave frequency and the machine's travel speed (Fig. 3), it is possible to control both the demolition depth and the gradation of the crushed material [11].

Fig. 3. Machine for ultrasonic rubblizing RMI [4]

A distinctive feature of this method is its ability to completely fracture concrete pavements throughout their full thickness without causing damage to the underlying subgrade. The fractured particles are typically oriented at an angle of approximately 45° relative to the pavement plane and interlock with each other, which facilitates load distribution over a larger surface area. The operational parameters of the machine are selected to ensure that deeper foundation layers remain intact [12]. Ultrasonic demolition is carried out using a specialized machine equipped with a vibrating working beam, operating with relatively low force (up to 10 kN) [4].

2.4. RUBBLIZING TECHNOLOGY

Rubblizing technology, i.e., the relaxation and fragmentation of existing concrete pavements, was developed and implemented in Wisconsin, USA, in the early 1980s [3]. Its objective was to create a load-bearing base layer before the placement of a new structural pavement layer using an asphalt overlay. The asphalt layer was intended to prevent reflective cracking by compacting and leveling to a uniform depth the existing damage and expansion joints in the concrete pavement [6].

The in-place fractured concrete pavement layer consists of irregularly sized and shaped blocks, which, when properly seated into the subgrade and compacted, form a dense, interlocked structure [3].

3. RESEARCH PROGRAM

3.1. EVALUATION OF THE EFFECTIVENESS OF RUBBLIZING METHODS

The field investigations on airport pavements were carried out using two rubblizing techniques, namely the Multi-Head Breaker (MHB) and the Guillotine Pavement Breaker (GPB).

Two test sections (TS) were selected for the study, located at two different airports in Poland, within functional airport elements (FAE) undergoing reconstruction as part of ongoing investment projects. The surface layers of the selected sections differed in service life but were constructed using identical technological solutions. The pavement construction of both test sections represented a typical composite system, i.e. a cement concrete base layer with asphalt concrete surface layers. As part of the test section preparation, the existing asphalt concrete layers were milled off, after which the rubblizing process was applied (MHB/TS-1, GPB/TS-2).

The adopted research program included the following tasks:

- evaluation of the effectiveness of each rubblizing method,
- testing the load-bearing capacity of the subgrade,
- testing the load-bearing capacity of the newly formed structural layer.

The effectiveness of the applied rubblizing techniques was verified under field conditions. The assessment consisted in determining the structural characteristics of the newly formed layer of crushed concrete rubble, i.e. the size of individual fragments and the ability of the layer to relax across its full thickness.

Figs. 4, 5, and 6 present photographic documentation from one of the test sections, illustrating the results obtained during the evaluation of the applied method.

Fig. 4. Measurements of the geometric dimensions of the fractured concrete rubble [9]

Fig. 5. Verification of the depth of stress relief in the cement concrete layer [9]

Fig. 6. View of the stress-relieved cement concrete layer on one of the test sections [9]

3.2. SUBGRADE BEARING CAPACITY TESTS

The bearing capacity tests of the subgrade directly beneath the relaxed layer were carried out before and after its relaxation. The bearing capacity of the subgrade was determined based on measurements taken with an SDS probe (Dynamic Cone Penetrometer – DCP) and an HWD (Heavy Weight Deflectometer). Based on the obtained results, the influence of the relaxation of the cement concrete layer (single-layer system) on the bearing capacity of the subgrade located directly beneath this layer was determined (the *CBR* index and deformation modulus E were determined). The required value of E for the subgrade was adopted as 120 MPa.

Fig. 7 shows the DCP subgrade bearing capacity test being carried out at one of the TS.

Fig. 7. Subgrade bearing capacity testing with the DCP probe on one of the test sections [9]

3.3. BEARING CAPACITY TESTS OF THE NEWLY FORMED LAYER (CONSTRUCTION)

The bearing capacity tests of the newly formed layer (construction) after the relaxation of the cement concrete layer (single-layer system) were carried out using the VSS apparatus and the HWD (Heavy Weight Deflectometer). As a result of the field measurements, the deformation moduli of the relaxed structure (E_1 and E_2), the deformation index I_0, and the substitute modulus E_z were determined. In addition, based on the HWD measurements, the modulus of elasticity E of the newly formed structural layer made of crushed concrete rubble was determined (back-analysis).

The following required values were adopted:

- E_2 (E_z) > 200 MPa,
- E > 400 MPa.

Figs. 8 and 9 show the bearing capacity tests of the newly formed layer (construction) at one of the test sections.

Fig. 8. Bearing capacity test with the VSS apparatus on one of the test sections [9]

Fig. 9. Bearing capacity test with the HWD device on one of the test sections [9]

4. TEST RESULTS AND ANALYSIS

4.1. VERIFICATION OF RUBBLIZING EFFECTIVENESS

The obtained test results are presented in accordance with the adopted testing program.

Based on *in situ* verification of the effectiveness of the evaluated rubblizing methods, it was found that for both MHB and GPB, the size (diameter) of the resulting concrete rubble blocks did not exceed the declared value of 310 mm.

In addition, approximately 75% of the rubble pieces had dimensions not greater than:

- in the lower half of the slab – 230.00 mm,
- in the upper half of the slab – 75.00 mm,
- on the slab surface – 50.00 mm.

However, in the case of GPB, to achieve the declared rubble dimensions, it is necessary to pass the machine twice over the relaxed surface, i.e., in both parallel and perpendicular directions.

4.2. SUBGRADE BEARING CAPACITY TESTS

The parameters of the subgrade directly beneath the pavement were determined in accordance with defense standards NO-17-A500:2016 [13] and NO-17-A503:2017 [14]. The subgrade bearing capacity was determined based on DCP measurements (before the rubblizing procedure) [15] and HWD measurements (before and after the rubblizing procedure).

To determine the subgrade bearing capacity, the following were used:

- *CBR* index values,
- modulus values,
- correlation relationship: $E = 10 \cdot CBR$ [16].

According to the requirements of the above-mentioned standards, the subgrade bearing capacity category should be determined based on the California Bearing Ratio – *CBR* [%], calculated in accordance with the formula (1):

$$CBR = 292 / DCP^{1.12}, \tag{1}$$

where:

CBR – California Bearing Ratio [%],

DCP – cone penetration per blow [mm].

The SDS probe soundings were carried out at three measurement points located in the cores drilled, to a depth of 0.85 m below the pavement construction level. The results of the subgrade bearing capacity test with the DCP probe are presented in Table 1.

Table 1. Results of the subgrade bearing capacity test with the DCP probe [9]

Test section	Measurement point no.	CBR [%]
TS-1	1	8.8
	2	11.7
	3	11.5
	Average	10.7
TS-2	1	10.2
	2	18.1
	3	3.9
	Average	10.7

Using the relationship between *E* and *CBR*, the average value of the subgrade deformation modulus *E* (before rubblizing) in both cases was 107 MPa.

Based on the HWD measurements, the values of the subgrade deformation modulus $E_0(r)$ were determined using the relationship (2):

$$E_0(r) = \frac{(1-v^2)\cdot q \cdot a^2}{r \cdot u(r)}, \tag{2}$$

where:

$E_0(r)$ – surface modulus at a distance r from the center of the loading plate,

a – plate radius,

v – Poisson's ratio,

u – deflection at the measurement point,

q – stress under the loading plate.

The obtained values of the subgrade deformation modulus *E* are presented in Table 2.

Table 2. Subgrade deformation modulus values *E* [9]

Test section	Subgrade deformation modulus *E* [MPa]	
	before rubblizing	after rubblizing
TS-1	100	130
TS-2	140	160

Based on the obtained test results, it can be concluded that the relaxation of the cement concrete layer using the MHB and GPB methods improves the bearing capacity of the subgrade directly beneath this layer.

4.3. BEARING CAPACITY TESTS OF THE NEWLY FORMED LAYER (CONSTRUCTION)

The bearing capacity tests of the newly formed layer (construction), after the relaxation of the cement concrete layer (single-layer system), were carried out using the VSS apparatus and the HWD (Heavy Weight Deflectometer).

The bearing capacity tests with the VSS apparatus were performed in accordance with standard PN-S-02205:1998 [17]. The deformation modulus E_1 and E_2 were calculated using the formula (3):

$$E_{1.2} = \frac{3 \cdot \Delta_p}{4 \cdot \Delta_s} \cdot D\,, \tag{3}$$

where:

Δ_p – increase in unit load within the specified range [MPa],

Δ_s – corresponding increase in deformation for the adopted unit load range, i.e., 0.25-0.35 MPa (layer system/after removing the wearing course) [mm],

D – diameter of the loading plate (300 mm).

Based on the values of the deformation modulus, the deformation index I_0 was calculated using the relationship (4):

$$I_0 = \frac{E_2}{E_1}\,. \tag{4}$$

The results obtained from the VSS apparatus tests are presented in Table 3.

Table 3. Results of the VSS apparatus tests [9]

Test section	Measurement point no.	E_1 [MPa]	E_2 [MPa]	I_0 [–]
TS-1	1	102	225	2.2
	2	113	250	2.2
	3	78	205	2.6
TS-2	1	50	205	4.1
	2	48	173	3.6
	3	52	161	3.1

Based on the results obtained, it was found that in the case of GPB ($I_0 > 2.2$), it is necessary to improve the grading of the layer prior to compaction.

Measurements with the HWD device were performed at randomly selected points. The test consisted of measuring elastic deflections, based on which substitute modulus values E_z were determined using the relationship (5):

$$E_Z = \frac{2 \cdot q \cdot a}{u(0)}\,. \tag{5}$$

In addition, based on the HWD measurements, the elasticity modulus E of the newly formed construction layer made of crushed concrete rubble was determined (back-analysis). The results obtained from the HWD tests are presented in Table 4.

Table 4. Results of HWD tests [9]

Test section	E_Z [MPa]	E [MPa]
TS-1	202	650
TS-2	227	650

Based on the obtained results, it was concluded that the newly formed layer of crushed concrete rubble, after prior compaction in accordance with technological requirements, met the adopted bearing capacity requirements in the case of both methods.

5. CONCLUSIONS

Based on the conducted analysis, the following conclusions were drawn:

1. Rubblizing technology was initiated in the USA as early as the 1980s. In Poland, it was applied for the first time in 2009. Since then, the number of projects where it has been used has been steadily increasing. This results not only from the fact that our experience in this area is much broader than it was a few or several years ago, but also from the requirements of modern road and airfield construction. Current environmental conditions increasingly require the use of recycled materials, primarily to reduce the negative environmental impact – by decreasing the consumption of natural resources and reducing CO_2 emissions. However, there are more benefits, as confirmed in this study.
2. In the authors' opinion, rubblizing is undoubtedly an example of a sustainable practice in infrastructure construction, which not only contributes to environmental protection but can also be regarded as a recycling method for concrete road and airfield pavements.
3. The results presented in this study clearly confirm the positive technical impact of rubblizing in carrying out repair (reconstruction) works of existing road and airfield pavements.
4. Based on the obtained results, it should be recognized that the relaxation of the cement concrete layer using

the MHB and GPB methods also improves the bearing capacity of the subgrade directly beneath this layer. This means that in the case of certain "anomalies" in the subgrade, it is possible to mitigate them without direct intervention in the subgrade, e.g., by injection. At the same time, the mechanical parameters achieved for the layer formed because of rubblizing are sufficient to consider it as a subbase for the designed road and airfield pavement constructions.

5. The use of rubblizing technology enables the reuse of "old" pavement constructions that are often intended for demolition. This translates into environmental benefits. The need for additional natural aggregates is eliminated, the amount of generated waste is reduced, and transport related to both the disposal of demolished material, and the delivery of new materials is limited.
6. Taking the above into account, rubblizing should be considered as having a positive impact on environmental, technical, and economic aspects and can be regarded as a recycling method for concrete road and airfield pavements.
7. As a direction for future work, the authors plan to perform rubblizing using the RMI method and then compare it with the methods described in the article. In the next step, the authors intend to attempt to identify environmental aspects associated with the use of rubblizing.

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Zastosowanie technologii rubblizingu w recyklingu nawierzchni drogowych i lotniskowych

Streszczenie: Współczesne budownictwo drogowych i lotniskowych nawierzchni betonowych coraz częściej wykorzystuje materiały z recyklingu jako kluczowy element zrównoważonego rozwoju. Stosowanie materiałów pochodzących „z odzysku" pozwala nie tylko ograniczyć negatywny wpływ na środowisko – zmniejszając zużycie surowców naturalnych i emisję dwutlenku węgla, ale także przyczynia się do obniżenia kosztów inwestycji. Jedną ze skutecznych metod recyklingu w budownictwie nawierzchni drogowych i lotniskowych jest technologia rubblizingu. Polega ona na odprężeniu (kruszeniu) istniejącej nawierzchni z betonu cementowego jedną z dostępnych metod, takich jak: rezonansowa kruszenia nawierzchni (ang. *Resonant Pavement Breaker* – RMI), wielogłowicowego rozbijania (ang. *Multi-Head Breaker* – MHB) czy gilotynowego kruszenia nawierzchni (ang. *Guillotine Pavement Breaker* - GPB), a następnie wykorzystania powstałego przekruszu betonowego jako warstwy podbudowy przy remontach nawierzchni dróg i lotnisk. W artykule przedstawiono przykłady oraz wpływ zastosowania przekruszu betonowego w procesie remontu nawierzchni drogowych i lotniskowych. Rubblizing jest przykładem zrównoważonej praktyki w budownictwie infrastrukturalnym, która przyczynia się nie tylko do ochrony środowiska naturalnego, ale może być traktowany jako recykling drogowych i lotniskowych nawierzchni betonowych. Zaprezentowane w pracy wyniki badań jednoznacznie potwierdzają pozytywny wpływ rubblizingu w aspekcie technicznym prowadzenia prac związanych z remontem (przebudową) istniejących nawierzchni drogowych i lotniskowych.

Słowa kluczowe: drogi i lotniska, nawierzchnia betonowa, podbudowa, recykling, rubblizing.