Mix Optimisation for Cement Mixtures Made of R.A.P. and C&D

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Synopsis

The increasing traffic flows on road infrastructures significantly quicken the degradation time of the pavements efficiency characteristics.
As a consequence, the managing bodies are obliged to consider more frequent maintenance interventions, so as to guarantee high levels of both safety and comfort for users.
Therefore, considering the wide extension of the Italian road infrastructures, one could easily imagine the large amount of milled materials (R.A.P.) coming from maintenance.
Along with R.A.P., there is another waste material which is to be considered also: it is the so-called C&D, which basically belongs from the demolition of civil engineering structures.
Both materials involve serious environmental considerations, the need of new landfills being compulsory.
The re-use of these substances is the solution to this concern, and this reflects the current trend of finding alternative technologies for the use of waste materials.
Actually, waste materials recycling, including R.A.P. and C&D is one of the most interesting technical innovations, both the economical and environmental aspects being considered at the same time.
For this reason, this paper proposes the outcomes of an optimisation study on R.A.P. and R.A.P. + C&D mixes for the manufacture of cement admixtures for road infrastructures, based on mechanical and economical evaluations.

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Nowadays the recycling of waste materials is a very interesting matter for the international community both from the economical and environmental point of view.
In industrialized countries the use of natural resources has increased more and more in order to produce certain quantities of goods, whose duration is rather limited, and in order to satisfy such a high demand significant is the quantity of resources which are currently extracted.
Apart from the raw materials supplying, also the problem of waste materials disposal should be strongly taken into account, especially with respect to those materials coming from the construction and demolition of civil buildings.
Indeed, the materials adopted as aggregates in the construction of civil engineering buildings are taken from quarries and the waste stuff are sent to dump. In this way an environmental damage is perpetuated twice.
These discard, legally defined special wastes and called "civil inert materials" are made of:

- Bricks, plasters, tiles, concrete and ceramics coming from the demolition and reconstruction of civil buildings and or remaining from new structures;
- Milled asphalt binders or bituminous admixtures deriving from road pavements (RAP).

According to official data, the annual volumes of rubble from C&D (Construction and Demolition), produced in Italy, are some 20 millions tons, even though the quantity could be higher , with a recycling percentage of about 15%.
C&D material, in order to be re-used as aggregates, generally needs a selection process with the elimination of paper, plastic, wood and impurities, and concrete should be rid of steel; additionally, a further crushing is necessary to reduce the parts in smaller pieces.
There are two different working techniques for C&D, in fixed and mobile plant.
The latter has the advantage of a smaller managing and initial cost, but does not guarantee an adequate cleaning and control of the materials from the standpoint of the sieve analysis. The fixed plant might have the negative aspect of a delocalization, but on the other hand involves a better treatment of the C&D waste materials and a higher productivity, which compensates the increased transport costs.
The current plants allow for the separation of the C&D waste in three typologies: re-usable aggregates, light fraction (plastic, wood, paper, impurities) and metallic fraction.
Most of the fixed plants use the R.O.S.E. technology, which is an acronym for homogenized reutilization of constructions wastes.
RAP, indeed, is made of a high quantity of valued material made for the 95% of basaltic, siliceous or calcareous aggregates and for the 5% of bitumen, and can be completely used in roads constructions.
Asphalt bitumen can be hot or cold recycled by means of a fixed or mobile plant, so as to be re-used in road pavements after the regeneration of bitumen and the reintegration of further aggregates and binder.
Referring to the data available, the RAP quantities reused are rather small, which means that, if not sent to dump, this material will be piled up in the areas of the plant.
There are recycling examples for both materials in the field of road infrastructures, no matter the small quantities. The most commonly used techniques for RAP are hot or cold recycling for the manufacturing of asphalt bituminous binders.
Therefore the researchers dedicated themselves to the study of new techniques and methodologies in order to get to the reutilization of this waste material, so as to reduce the process of dump filling and not renewable resources extraction, the result being the availability of material competitive from the economical viewpoint and acceptable from the qualitative one.
This research aims at the optimization , based on mechanical and economical data, of milled RAP asphalt bitumen, of C&D and RAP + C&D rubble cement bond for the manufacture of cement admixtures for base and/or foundation layers of road and rail infrastructures.

ITALIAN STANDARDS

In order to respect the prescriptions of the member Countries, with the law decree n°22 issued on the 5th of February 1997 (called Ronchi Decree), Italy actuated three EEC norms: on waste materials (91/156/EEC), on dangerous waste (91/689/EEC), on packaging and packaging waste (9/162/EEC), and arranged the instructions provided so far.
The Ronchi Decree, respecting the EEC instructions, imposes the human health and the environment protection in the activity of reuse and disposal of waste.
Indeed, with the law decree n° 22/97the regulations on waste materials has change and its main principles clarified the aim of environment protection and of responsibilization of all the subjects involved in the products life cycle.

In Italy the individuation of non dangerous products subjected to the simplified disposal reuse procedures indicated in Artt, 31 and 33 of the law decree n° 22/97 occurred with the ministerial decree issued on the 5th of February 1998 on the “Technical Standards for the recycling of non dangerous waste”.
Referring to the laws in force, waste can be divided in urban or special, dangerous or not, and the different typologies of waste coming from the different production processes are labelled with the CER codes (European waste catalogue), which are ordered on the basis of the place of origin and of the danger characteristics.
The European Community Commission decided, on the 3rd of May 2000 and afterward modified this issue with the decisions 2001/118/CE, 2001/119/CE and 2001/573/CE, to adopt the new waste list which the member States should respect from the 1st of January 2002.
For the sake of brevity the CER codes are not reported at this stage, the only information being the fact that group “17” non dangerous materials “Refusal of buildings and rubble (C&D)” can be used in the field of road constructions.

CEMENT MIXTURES

It is well known that, in order to reduce the magnitude of the deformations deriving from the increasing number of passages of heavy vehicles and to withstand the stresses induced on road superstructures, cement mixture layers are manufactured.
Cement mixture is made of an admixture of aggregates coming from crushing activities of from natural formations, which has precise sieve sizes, with the addition of reduced quantities of 3% to 5% in weight cement and water [1].
The use in flexible pavements of a semi-rigid cement mixture base layer, allows the road to have a higher bearing capacity and fatigue resistance [2]. While in rigid pavements the cement mixture, used as foundation layer, apart from avoiding a strong jump of stiffness between the concrete element and the subgrade, allows a uniform laying of the concrete layer itself and, at the same time, it reduced the danger of cracks due to inhomogeneous displacements and to pumping [3].
The particle size of the cement mixture is fundamental for the good outcome of the admixture, and for this reason the CNR 29/72 Standards and the various prescriptions prescribe precise sieve analyses [4] [5].
Indeed, the behaviour of an admixture depends upon the fact that the particle size of aggregates could be closed to the lower or to the upper parts of the curves.
The curves next to the lower one furnish higher thickening rated and a smaller voids percentage, and therefore a higher compression strength.
The curves next to the upper one give, the binder quantity being unaltered, an increased flexural strength.
Therefore, for very strict curves ranges, it is possible to obtained rather defined and homogeneous mechanical characteristics, while in the opposite situation the results would be pretty dispersed.
The CNR BU n°29/72 Standards on cement mixtures proposes two sieve sizes, which should be used for two different kinds of cement admixtures: type A1 with reduced gap between the two curves, and type A2 with a wider gap, where the maximum size of aggregates must be smaller than 40mm.
The same Standards say that the cement rate in the mixtures is to be equal to 3% and 5%, that the Los Angeles weight loss of the aggregate should be lower than 30% and that the sand equivalent should be higher than 35 and 25, respectively for A1 and A2 classes.
From the mechanical point of view the material characteristics are to be evaluated, after seasoning at 20°C in a 90% humidity environment, by means of the free lateral compression expansion test on cylindrical specimens manufactured following the same procedure of the CBR ones.
The Standards fix a range within 3 and 7 MPa for the compressive strength at 7 days, so as to have a strong material, but not too stiff.
Moreover, some prescriptions ask also for a indirect traction strength (Brazilian test), determined on the same specimens, higher than 0.25 MPa.

EXPERIMENTAL INVESTIGATION

The research aims at the study of cement admixtures made with RAP milled bituminous asphalt and C&D demolition and construction material as aggregates. Therefore it is necessary to verify the possibility of using those materials and of optimising the mix design.
In particular, RAP is used as it is, without separating it from the bitumen of the aggregate, limiting the hardening action of cement-aggregate, while C&D, since it is made of different materials typologies, is to be studied chance by chance in order to define the mix design with the best performances from mechanical point of view.
The experimental investigation was conducted at the Road Construction Laboratory of the University of Basilicata – Potenza.
The first phase was based on the analysis of the recycled material and on their particle size definition, on the assessment of the sand equivalent E.S. and of their mechanical characteristics from the standpoint of impact resistance and Los Angeles abrasion.

The second part was based on the definition of the optimal particle size to be used in the admixtures preparation, made with different combinations of material (RAP, RAP and C&D, RAP and calcareous material, etc).
The specimens, prepared according to the CNR BU n°29/72 standards and adequately seasoned at 7 and 28 days, where subjected to the free lateral expansion compressive test and the the indirect traction one.

Description of the materials used

The following material were used:

1. RAP: milled asphalt coming from the milling of the binder and wearing course layers of the SS 658 Potenza-Melfi, made of 5% of bitumen and by siliceous aggregates. RAP has a sand equivalent value ES equal to 74, a Los Angeles coefficient equal to 20 and the particle size of Tab.1.
2. C&D: construction and demolition material coming from a crushing plant located near Salerno, mainly made of bricks, plaster, concrete and baked clay. C&D with the sieve analysis of Tab.1 has a sand equivalent of 42 and a Los Angeles coefficient equal to 28.
3. The first use limestone, coming from the quarry of Pantano – Pignola (PZ), with a sand equivalent equal to 85 and a Los Angeles coefficient equal to 23.
4. The cement used for the mix is a 325 Portland

Mix design

The definition of the mix design of the cement mixtures the particle size of aggregates plays a fundamental role. From the analyses carried on it was found that the C&D and RAP “as it is” curves are out from the limiting curves (Tab.1) and therefore a correctio0n from the point of view of the sieve analysis in necessary.
So as to define an optimal curve for these materials, different admixtures of cement mixtures were prepared, changing the grading curve without changing the cement rate, equal to 3.5%.
With every mixture, respecting the CNR standards, some specimens to be tested under free lateral expansion compression and indirect traction were prepared

Tab.1

Crivelli Setacci (mm)	Fuso ANAS AUTOSTRADE	Fuso CNR A_1	Fuso CNR A_2	C&D	RAP
40	100	100	100	100	100
30	80-100	100	100	77,51	97,06
25	72-90	65-100	65-100	71,44	94,61
15	53-70	45-70	45-78	56,48	79,13
10	40-55	35-60	35-68	46,76	70,51
5	28-40	23-45	23-53	34,29	49,25
2	18-30	14-30	14-40	24,23	31,8
0,42	8-18	6-14	6-23	6,18	10,19
0,18	6-14	2-7	2-15	1,32	6,1
0.075	5-10	-	-	0,18	5,41

Amongst all the analysed curves the Authors chose that one which furnished always good results in all the tests, which was that in the middle of the limiting Anas and Autostrade curves (Figure 1)
This curve was the basis of the previous investigation, in order to optimise the cement percentage to be used and the combination of the recycled material to use in the different mixtures.
As for the hydraulic binder, its rate was assessed by using it initially only in a mixture in percentages varying from 2% to 5%; afterward it was decided to use the following quantities on the mixture weight: 2.5%, 3.5% and 4.5%.
The choice of these percentages is motivated by the will to look for a valid cement mixture, without exceeding with the quantity of binder to be used..
The quantity of water adopted in the mixtures varied from 5% to 6%.
Per quanto concerne il legante idraulico, il suo tenore è stato definito impiegandolo inizialmente in una sola miscela in percentuali variabili dal 2% al 5%, pervenendo alla decisione ponderata di utilizzare nel prosieguo dello studio tenori pari a 2,5%, 3,5% e 4,5% rispetto al peso della miscela. La scelta di queste tre percentuali

è motivata dalla volontà di cercare un misto cementato valido, senza eccedere nella quantità del legante da utilizzare.
La quantità di acqua impiegata negli impasti variava tra il 5% ed il 6%.

Mixtures prepared

In this phase of the investigation the mixtures were realized using, at first, only the “as it is” RAP and C&D, without any correction from the particle size point of view, but only limiting the 0/25 mm dimensions. Subsequently the two materials were combined in different percentages and /or with virgin limestone, so that the mixture could respect the curve in Figure 1.
All the mixtures, including those unchanged from the grading curve point of view, but diversified with respect to the materials composition, were manufactured with three percentages of cement 2.5, 3.5 and 4.5%.
For the sake of brevity only the mixtures whose values were positive for a road use are reported, as well as those of the as they are recycled materials, précising that for the completeness of the study the mixtures were prepared using only virgin limestone as aggregate.
The composition of the aggregate in the proposed mixtures was diversified in this way:

1. CV mixture: 100% of virgin limestone, with Figure 1 curve;
2. C&D mixture: 100% C&D as it is with 0/25 grading (Tab.1);
3. C&D mixture:
4. C&D mixture cr: 100% C&D with reconstructed curve as in Figure 1;
5. 70C&D-30CV mixture: 70% C&D (40% of 0/5 dimensions and 30% of 5/25) and 30% of virgin limestone 15/25 (curve of Figure 1);
6. 50C&D-50CV mixture: 50% C&D (30% of 0/5 dimensions and 20% of 5/25) and 50% of virgin limestone 15/25 (curve of Figure 1);
7. 70C&D-30RAP mixture: 70% C&D (40% of 0/5 dimensions and 30% of 5/25) and 30% of R.A.P. 15/25 (curve of Figure 1);
8. 50C&D-50RAP mixture: 50% C&D (30% of 0/5 dimensions and 20% of 5/25) and 50% of R.A.P. 15/25 (curve of Figure 1);
9. RAP 1 mixture (0/25): 100% of R.A.P. as it is with 0/25 aggregates (Tab.1);
10. RAP 2 mixture (0/5-5/25): 30% of R.A.P. 0/5 and 70% of R.A.P. 5/25;
11. RAP cr mixture: 100% of R.A.P. with reconstructed curve as in Figure 1;
12. 70RAP-30CV mixture: 70% R.A.P. (40% of 0/5 dimensions and 30% of 5/25) and 30% of virgin limestone 15/25 (curve in Figure 2);
13. 50RAP-50CV mixture : 70% R.A.P. (40% of 0/5 dimensions and 30% of 5/25) e 30% of virgin limestone15/25 (curve of Figure 1).

For each mixture six specimens were manufactured and for each of them the blend was performed so that it could be accurately mixed, avoiding the components segregation while mixing.
After some minutes from the mixture with water and cement, everything was mixed up again in order to avoid the phenomenon of the binder false setting. Therefore the mixture, before the compaction in the Proctor mould [6] was allowed to stand for about two hours, in order to let the water permeate through the pores and moisten all the material lumps.
The specimens were seasoned at 7 and 28 days in a 90% humid environment at about 20°C. The first 24 seasoning hours happened in the tag, and afterwards they were extracted.
Four specimens were subjected to the free lateral expansion compression test and two to the indirect traction (Brazilian) one.

ANALYSIS OF RESULTS

Free lateral expansion compression

For each mixture the free lateral expansion compression mean braking value was determined at 7 and 28 days. For a higher knowledge of the stress-strain state of the specimens under load the test was instrumented so as to get to an automated acquisition of data.
Figure 2 illustrates, for the sake of brevity, the charts of three mixtures seasoned at 7 days before testing them under free lateral expansion compression.
The tested materials were the following, all of them having a 4.5% cement rate: mixtures CV, 50C&D-50CV and 50C&D-50RAP.
From the analysis of the three charts it is clear that the cement mixture, where the virgin limestone is present, shows the highest values with small deformations, while in presence of 100% recycled material, the curves, even though the resistance values area high, are rather flattened as a consequence of an increased deformability, anyway rather limited (e = 0,015 - see Figure 2).

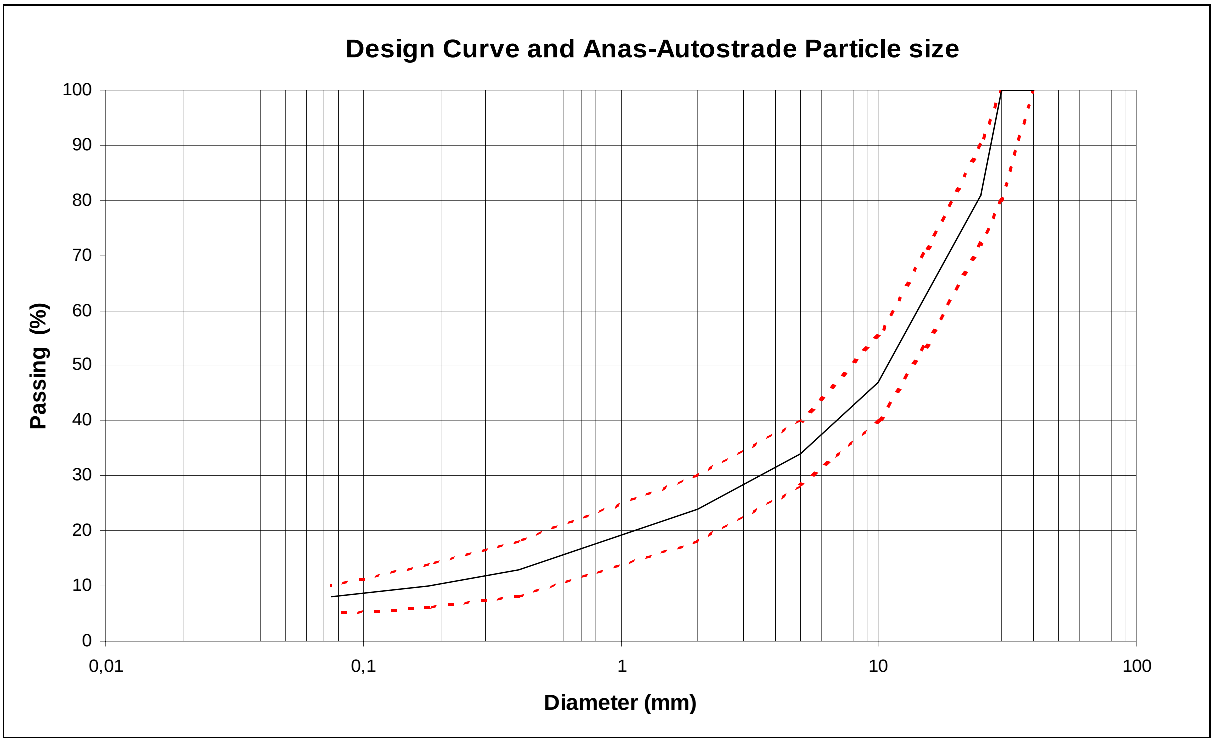

Figure1: Design Curve

The specimens pressed following the CNR Standards procedures gave the results included in Tab.2 whose diagrams are reported in Figure 3, distinguished as function of the type of mixture and of the cement quantity.
These data, in order to be accepted, are to be included within the range 3-7 MPa, the latter being the limit for an excessive stiffness of the concrete mixture limit and for an excessive shrinkage, while the former a poor quality of the material.
The compression test at seven days showed the impossibility of adopting only C&D and RAP as they are for the manufacture of cement mixtures, considering that only the C&D with 4.5% of cement the lower limit of 3 MPa was reached.
Indeed the recycled materials only after a correction of the grading curve of Figure 1 and with cement rates of 3.5% and 4.5% showed a positive behaviour in compression with values higher than 3 MPa, getting, in the case of the C&Dcr and RAPcr mixtures with 4.5% of cement, respectively, to 3.78 and 3.73 MPa.
The results obtained with the C&Dcr mixes confirm the importance of a correct particle size for this kind of mixtures, which can be achieved only in fixed plant.
The mixtures 70C&D-30RAP indicated in Tab.2 and Figure 3 recorded compression strengths comparable to those of C&Dcr and RAPcr, reaching the minimum value of 3 MPa from 3.5% of cement and 3.36 MPa with 4.5% of binder. The same thing happened for the 70RAP–30CV mixtures which presented strengths equal to 3.10 MPa only with cement rates higher than 3.5% and to 3.87 MPa with 4.5%.
In all the other mixtures where virgin limestone was adopted, the acceptance limit was overtaken already with 2.5% of cement, obtaining the maximum absolute value of 5.30 MPa with the 50C6D-50CV mixture with 4.5% of cement, and this was the confirmation of the fact that the use of virgin aggregates with cement is advisable rather than the other two materials.
It is to specified that in Tab.1 and Figure 2 also the data of traditional cement mixtures with the particle size described in Figure 1 are reported. These values obviously are included in the range 3-7 MPa and are higher than the minimum also with cement rates equal to 2.5%.

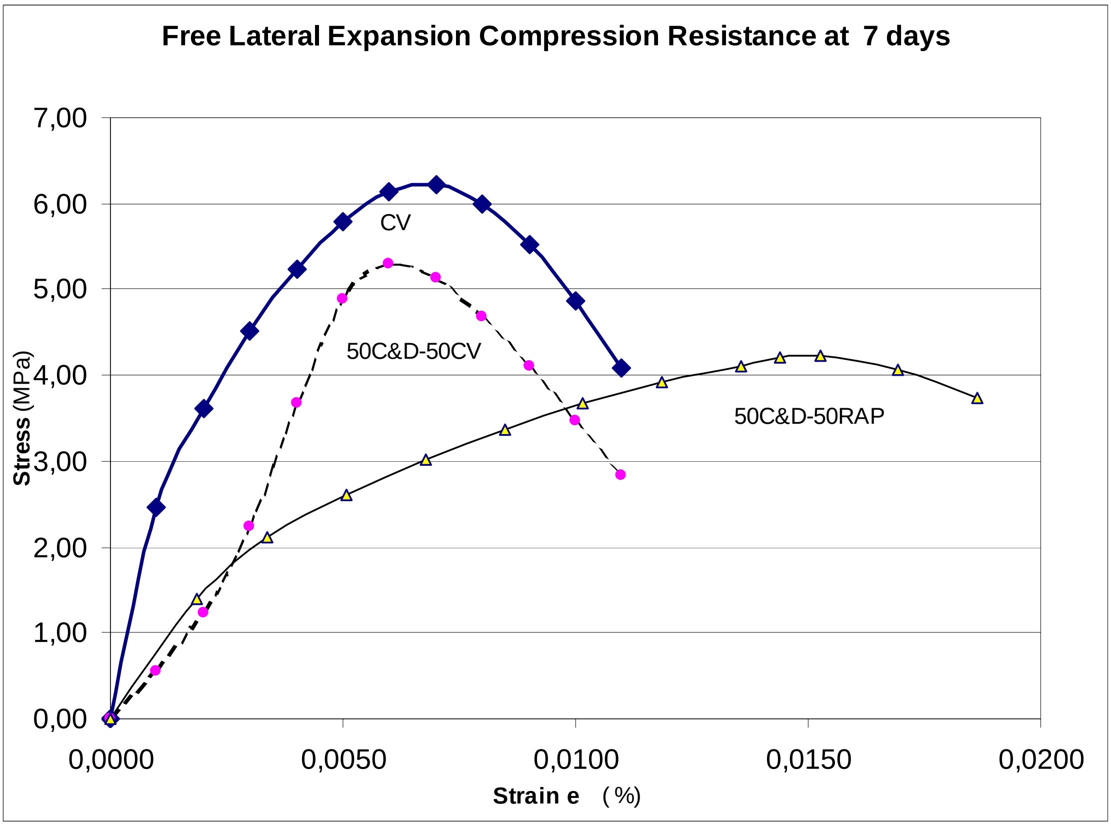

Figure 2

Tab. 2

% CEMENT	SEASONING	FREE LATERAL EXPANSION COMPRESSION RESISTANCE VALUES [MPa]											
		CV	**C&D**	**C&D cr**	**70C&D-30CV**	**50C&D-50CV**	**70C&D-30RAP**	**50C&D-50RAP**	**RAP 1 (0/25)**	**RAP 2 (0/5-5/25)**	**RAP cr**	**70RAP-30CV**	**50RAP-50CV**
2,5	7 days	4,24	2,08	2,81	3,48	3,73	2,59	3,17	1,31	2,07	2,92	2,65	3,15
3,5		5,23	2,50	3,26	3,78	4,05	3,04	3,46	1,70	2,51	3,25	3,10	3,82
4,5		6,21	3,00	3,78	4,87	5,30	3,36	4,22	2,26	2,88	3,73	3,87	4,75
2,5	28 days	4,46	2,19	2,96	3,66	3,93	2,73	3,34	1,53	2,40	3,51	3,35	3,92
3,5		5,46	2,62	3,42	3,96	4,24	3,18	3,62	2,02	2,90	3,97	3,94	4,69
4,5		6,44	3,12	3,92	5,05	5,49	3,48	4,38	2,78	3,54	4,64	4,80	5,85

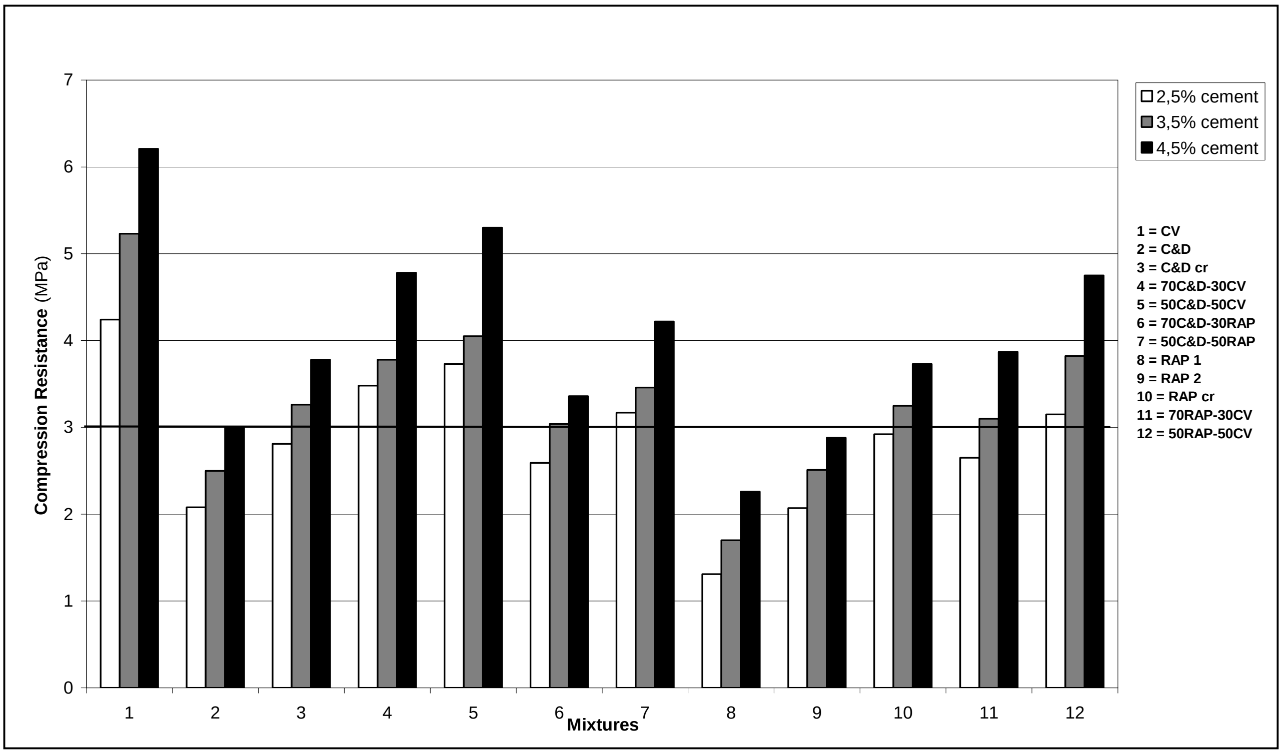

Figure 3: Free Lateral Expansion Compression Resistance Values at 7 days

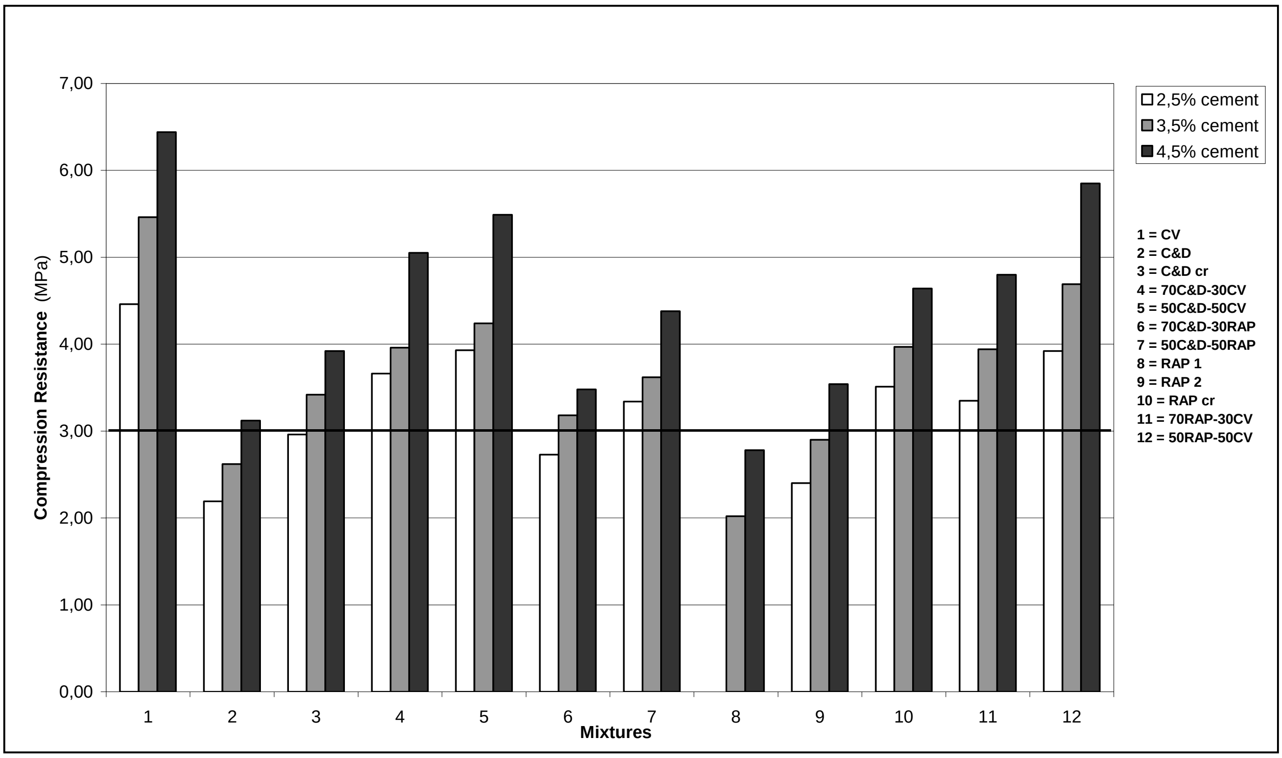

Figure 4: Free Lateral Expansion Compression Resistance Values at 28 days

Compression resistance for medium-high seasoning times is not expressly requested from the standards, since the 7 days one is sufficient for the evaluation of the possibilities of employment of the material.
In the investigation so as to have a higher knowledge of the behaviour of the material with time and of its capability of creating a strong effective structure, the resistance of the specimens at 28 days of seasoning were assessed.
The behaviour of these values confirmed the reciprocal relations between the mixtures adopted after 7 days, highlighting the increases of all the values included in the range 3-30%.

Also the C&D and RAP 2 with 4.5% binder mixtures at 28 days of seasoning are higher than the minimum value of 3 MPa, while the others, that do not reach the value at 7 days are not able to do this not even after 28 days.

Indirect traction

Every mixture was subjected to the in direct traction test at both 7 and 28 days of seasoning. The corresponding results at rupture are included in Tab.3 and in Figures 5 and 6.

Tab. 3

% CEMENT	SEASONING	INDIRECT TRACTION RESISTANCE VALUES [MPa]											
		CV	**C&D**	**C&D cr**	**70C&D-30CV**	**50C&D-50CV**	**70C&D-30RAP**	**50C&D-50RAP**	**RAP 1 (0/25)**	**RAP 2 (0/25-5/25)**	**RAP cr**	**70RAP-30CV**	**50RAP-50CV**
2,5	7 days	0,56	0,18	0,44	0,32	0,49	0,24	0,36	0,12	0,16	0,27	0,24	0,29
3,5		0,83	0,21	0,50	0,38	0,79	0,37	0,47	0,17	0,22	0,33	0,30	0,41
4,5		1,05	0,36	0,70	0,62	0,89	0,48	0,66	0,25	0,32	0,42	0,41	0,53
2,5	28 days	0,67	0,21	0,51	0,38	0,57	0,29	0,42	0,16	0,19	0,31	0,29	0,36
3,5		0,92	0,23	0,56	0,43	0,87	0,42	0,52	0,22	0,26	0,36	0,37	0,50
4,5		1,12	0,38	0,74	0,65	0,94	0,51	0,69	0,32	0,37	0,44	0,47	0,61

The minimum value of resistance for this kind of test, provided for in the different specifications and highlighted in the diagrams of Figures 5 and 6, is equal to 0.25 MPa.

The values of the indirect traction resistance do follow the same trend of the compression ones, the only difference being the fact that in this case all the mixtures with the 4.5% of binder, already after 7 days, overtake the minimum value of 0.25 MPa (Tab.3 and Figure 5).

The admixtures, prepared with the curve of Figure 1, after 7 days showed a good behaviour under traction, also with small cement rates. In particular the C&Dcr one with 2.5% of cement reaches 0.44 MPa and with 4.5% gets to 0.70 MPa, while the RAPcr ones with 2.5% and 4.5% of cement exhibit a value respectively equal to 0.27 MPa and 0.42 MPa (Tab.3 and Figure 5).

Referring to the mixtures made with the recycled materials, the maximum value of resistance at 7 days was exhibited by the 50C&D-50CV mixture at 4,5%, the value being 0.89 MPa. This value was reduced to 0.53 MPa in the 50RAP-50CV mixture with 4,5%, where C&D was changed with RAP.

The mixtures with RAP, even though the results were good, furnished smaller resistances compared to C&D, confirming the existence of a weaker bound between cement and RAP compared to that between cement and C&D. This is due to the fact that in RAP the aggregate is partially or completely coverd by bitumen, whose adhesion capacity to cement is still unknown, because of the different nature of the materials.

The indirect traction values at 28 days of seasoning, confirmed the tendency recorded at 7 days, showing also an increment of all the values from about 5% to 30% (Tab.3 and Figure 6).

Mixtures with RAP "as it is" and with C&D "as it is" did not reach the minimum value of 0.25 MPa even aftar 28 days with a binder content lower that 2.5%. While in all the other circumstances the already good performances registered at 7 days were improved, obtaining the maximum value of resistance of 0.94 MPa with the 50RAP-50CV mixture at 4,5%.

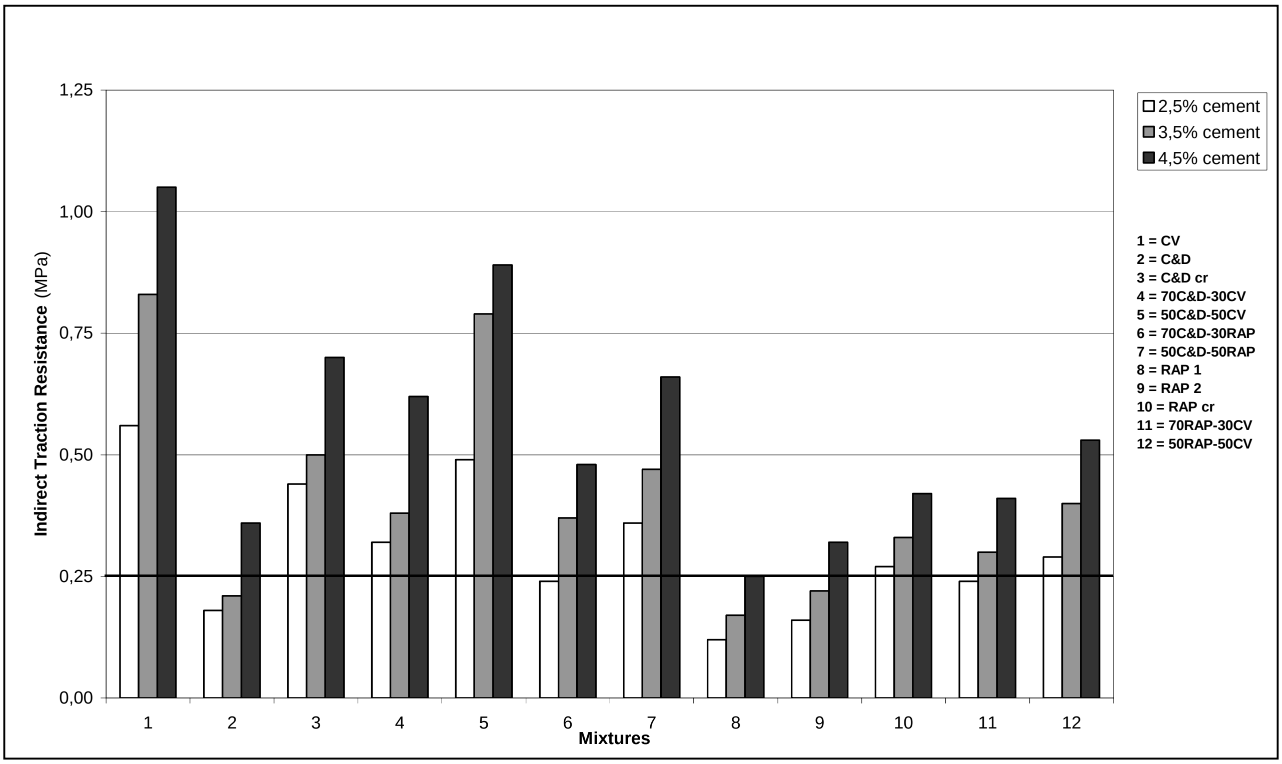

Figure 5: Indirect Traction Resistance Values at 7 days

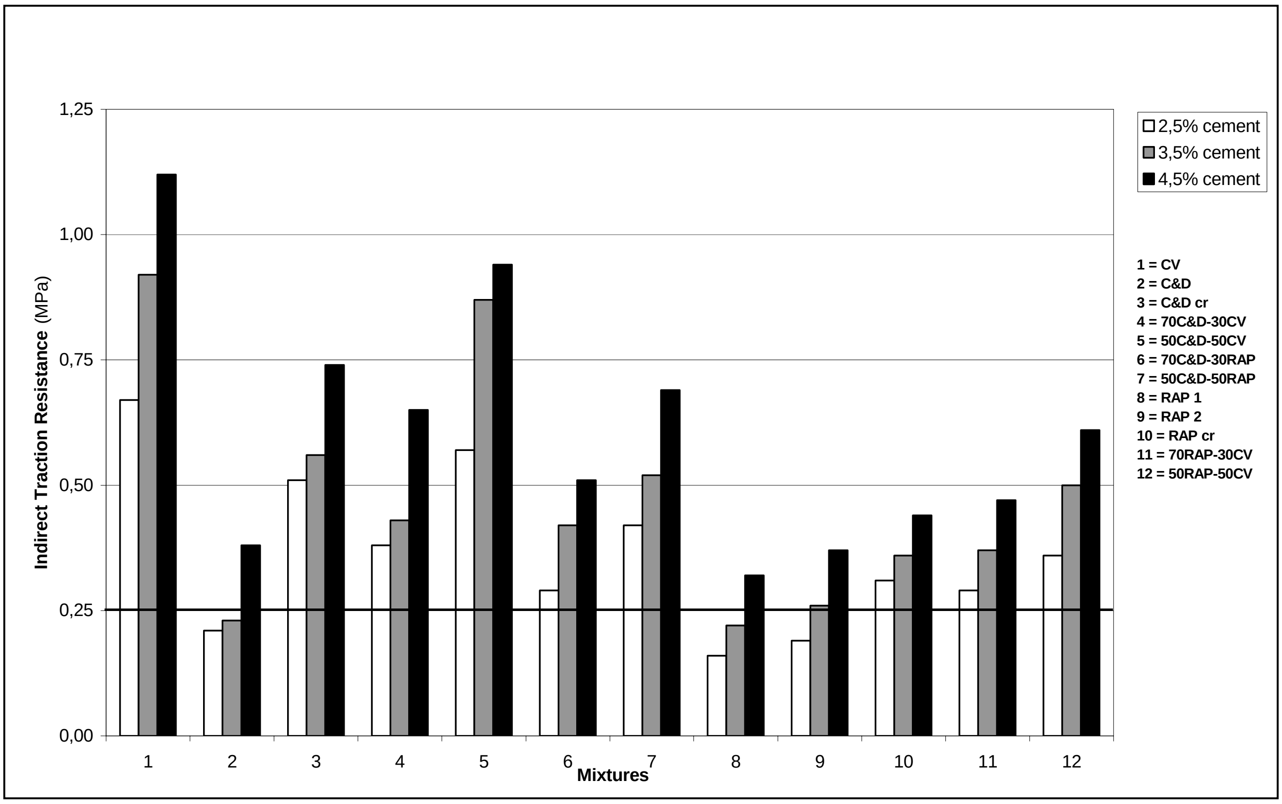

Figure 6: Indirect Traction Resistance Values at 28 days

ECONOMICAL ANALYSIS

From the results of the investigation it was seen that it is possible to employ C&D and RAP in cement admixtures, according to precise percentages defined with a correct mix design. In Tab.2 and 3 and in Figures 3-6 the mechanical performances of the mixtures are reported, including the first use limestone CV at 2.5%, 3.5% and 4.5% of cement, traditionally adopted for road pavements.
In order to complete the investigation the Authors wanted to find out, amongst the proposed mixtures, which one furnishes the higher economical convenience, as a consequence of the optimal determination of the recycled quantity (C&D and/or RAP) which can be used in a concrete mixture, monetizing the possible money saving due to the use of such materials.
For this reason the attention was concentrated on some mixtures which at 7 days overtook the minimum resistance value in compression, equal to 3 Mpa, considering the following parameters in the evaluation:

- pavement life cycle;
- mechanical performances of the material;
- costs of each component;
- manufacturing and laying costs;
- discharging costs of the resulting materials.

The pavement life cycle depends upon the mechanical characteristics of the layers as well as on the stresses, seen as the number of passages of equivalent axle heavy vehicle.
The analysis was conducted on a semi-rigid pavement included in the "Catalogo delle pavimentazioni stradali" [7] made of the following:

- 5 cm asphalt wearing course;
- 5 cm asphalt binder layer;
- 15 cm asphalt base layer;
- 25 cm concrete mixture foundation layer;
- Resilient modulus of the sub-grade Mr=90 N/ mm^2.

The calculation of the pavement life cycle was conducted with the AASHO Interim Guide method which considers the determination of the number of passages of equivalent 8.2 T axles (N8.2) which a superstructure, with a thickness index Is can withstand along its life cycle.
The mean daily traffic TGM was considered equal to 5000 vehicles in both directions with a prevision of an annual incremental rate r equal to 5% and a heavy vehicle traffic Pvp equal to the 10% of TGM, made of 8.2 tons axles vehicles.
Once the structural number was calculated and the final value of the index of suitability Pf was imposed to be 2.5, the number of 8.2 tons passages to be compared with the data of the traffic on the road was deduced.
In the determination of the cost of the cement mixture layer was made referring to the price list of the Civile Engineers of the province of Potenza updated to 2004 and to the current market prices.
Cement and aggregates cost were considered along with the production, the transportation and laying of the concrete mixture ones: the costs of the transportation to dump of RAP and C&D and of the milling activity of asphalt were considered also.
The prices of 325 cement and of the aggregates used for the evaluation were respectively 8,57 €/quintal and 6,15 €/m^3; the manufacturing cost of a cement mixture layer, excluded the material provision is equal to 11,00 €/m^3. The cost of transportation to dump of C&D and RAP within 10 km is 0,46 €/m^3, while the dump acceptance of the same materials is 8,00 €/m^3. Moreover, for C&D it was estimated an incidence of the recycling activity equal to 4,00 €/ m^3 for C&D and of the milling of RAP equal to 0,50 €. m^2/m^3 for each cm of milled pavement.
The cost analysis was completed with the determination of the residual value of the pavements, referred to that of highest life cycle and equal to 22.22 years. Therefore the residual values at 22.22 years of the other kinds of pavements with a lower life cycle were assessed, in the hypothesis that they were reconstructed in the meantime. The costs were actualized with an interest rate equal to 3%.
Applying the known formula of financial math the net cost of a cubic meter of cement mixture referred to the 16 mixtures considered is determined (Tab. 4)
Table 4 shows that C&D and RAP can be conveniently used in the manufacture of base or foundation layers in cement mixture, even though mixed with each other or integrated with virgin limestone.
From the economical analysis it was found that the mixtures made with 2.5%, 3.5% and 4.5% of 50C&D-50RAP have the lower net cost, ranging from 33,57 €/m^3 to 38,52 €/m^3, with a further money saving compared to the other mixtures integrated with virgin limestone.
The economical convenience is even more evident comparing these mixtures to the traditional ones made of only virgin material. Also the 4.5% 70C&D-30CV mixture gives a saving slightly lower and in any case has good mechanical resistances at low and long seasoning, definitely higher than those without integration with natural aggregates.

Tab.4

Mixtures	**Cement** (%)	**Initial value** (€/m^3)	**Annual rate Quote** (€)	**Final cost** (€/ m^3)
70C&D-30RAP	4,5	26,39	2,32	42,80
50C&D-50RAP	2,5	20,70	1,82	33,57
50C&D-50RAP	3,5	23,32	2,05	37,82
50C&D-50RAP	4,5	25,94	2,11	38,42
70C&D-30CV	2,5	26,28	2,31	42,62
70C&D-30CV	3,5	28,90	2,54	46,87
70C&D-30CV	4,5	31,52	2,22	38,70
50C&D-50CV	2,5	29,25	2,57	47,44
50C&D-50CV	3,5	31,87	2,69	49,40
50C&D-50CV	4,5	34,49	2,35	40,33
CV	2,5	36,69	2,98	54,34
CV	3,5	39,31	2,68	45,97
CV	4,5	41,93	2,61	41,93
70RAP-30CV	4,5	29,96	2,63	48,59
50RAP-50CV	3,5	30,76	2,70	49,89
50RAP-50CV	4,5	33,38	2,43	42,99

CONCLUSIONS

This paper deals with one of the most commonly discussed topic of the recent years, which is the recycling of waste materials coming from demolition and/or construction activities of civil engineering.

With the investigation the possibility of using the materials C&D coming from demolition and construction and RAP from asphalt milling into concrete mixtures as aggregates as partial on total alternative to the virgin aggregate of first use was verified.

In the realization of concrete mixtures, RAP was prepared without separating the bitumen from aggregates.

In order to optimize the mix design of concrete mixture in the experimental phase several mixtures with recycled materials have been prepared, amongst which the RAP “as it is” ones and the C&D “as it is” one gave the worse results, smaller than the minimum prescribed by the Standards.

The grading curve, which allowed to obtain the better results, is that one included into the upper and lower curve of ANAS and Autostrade, described in Figure1. The mixtures have been prepared with cement rates of 2.5, 3.5 and 4.5%.

Tables 2 and 3 and Figures 3-6 include the data of the mechanical performances of the mixtures, from the standpoint of free lateral expansion compression and indirect traction resistance after 7 and 28 days of seasoning, with cement rates of 2.5, 3.5 and 4.5%.

In order to have a comparison with the same particle size traditional cement mixtures have been realized, utilizing first use limestone

Most of the mixtures corrected from a sieve particles point of view overtook the minimum values requested with 3.5% and 4.5% cement, reaching a compression resistance of 5,30 MPa and 4,87 MPa respectively in 50C&D-50CV and 70C&D-30CV mixtures at 4,5%.

Good results have been also exhibited by the 50C&D-50RAP mixtures which, after 7 days, furnished compression resistances within 3,17÷4,22 Mpa and in traction resistances within 0,36÷0,66 MPa.

C&D integrated with quarry aggregates furnished better results compared to RAP with quarry material.

All mixtures confirmed that the material strength increases with the increase of the binder and virgin limestone content, as well as with seasoning time.

Finally on some mixtures which overtook the requested values, included those with virgin limestone CV, an economical analysis has been performed, based on pavements life cycle determined with the AASHO Interim Guide method and on the prices of materials and manufacturing in Basilicata, updated to 2004.

From the experimental and economical results it is evident the mechanical and economical convenience of the 50C&D-50RAP mixtures with 2,5%, 3,5% and 4,5% of cement, compared to the others.

From the study it results that C&D and RAP can be adopted, with the appropriate percentages, in cement mixtures for base or foundation layers of road and railways structures.
Anyway, it must be précised that the punctual correction of the particle size can be achieved only with a fixed recycling plant, since nowadays mobile plants do not offer the appropriate guarantee.
In conclusion the positive outcomes of the investigation do induce the Authors to solicit the Administrations to consider into their prescriptions the use of C&D and RAP in cement mixtures, because of their performance, environmental and economical validity.

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