PRIVATE & CONFIDENTIAL

Department of the Environment, Transport and the Regions

RESEARCH PAPER 815

USE OF RECYCLED AGGREGATES AS CLAY PIPE BEDDING

J.D.Barnes and C.Beardmore

Date: 1999

YOUR PARTNER IN MATERIALS AND TECHNOLOGY

CERAM

Research Paper 815

Use of Recycled Aggregates as Clay Pipe Bedding

The work described in this report (contract reference 39/3/420 cc1397) was funded by the Department of the Environment, Transport and the Regions under the Partners in Technology Programme. The report is published on behalf of DETR but any opinions expressed are not necessarily those of the funding department

DETR
ENVIRONMENT
TRANSPORT
REGIONS

CONTENTS

EXECUTIVE SUMMARY

The structural performance of rigid pipes has traditionally been improved by using naturally occurring gravel aggregates. The most appropriate size gradings for use in this application were determined during extensive laboratory investigations carried out by British Ceramic Research Limited in the 1960's.

As a result of the increasing difficulties being experienced in obtaining supplies of primary naturally occurring aggregates there is currently a move towards the use of secondary material, in particular recycled, aggregate produced from construction demolition waste.

The objective of the work, carried out under DETR Contract 39/3/420 cc 1397, was to address this issue by determining whether recycled aggregates could in fact be used as an alternative bedding material for drainage applications. The work programme involved:

- Developing a test rig capable of replicating the earlier work carried out on natural aggregate bedding
- Validating the test rig by carrying out tests on prescribed gravel gradings
- Evaluating the performance of a total of 9 recycled aggregates. These comprised 5 aggregates that had been specifically selected and a further 4 collected from active demolition sites. Eight of the aggregates were supplied as nominal 20mm down gradings whilst the ninth was sized between 20 and 10mm.

The test work carried out on the recycled aggregates produced pipe displacements significantly higher than those measured on comparable natural gravel bedding. The greater arcs of contact between the pipes and the recycled aggregate bedding, concomitant with the increased displacements, gave increased bedding factors (load ratios) so that values in excess of the 1.1 specified for class N bedding materials were measured on all nine recycled aggregates.

The guidelines for class N bedding also specify a maximum compaction fraction of 0.3. Here values measured on 7 of the recycled aggregates ranged from 0.21 to 0.31. Sieve analyses and visual inspections carried out on the individual aggregates suggested that reasonable care over selection and grading of the aggregates should ensure that compaction fractions below 0.3 are obtained.

Overall the investigation has indicated that satisfactory load ratios and acceptable displacements could be achieved, at the loads likely to be applied in practical site situations, using bedding materials comprising recycled construction and demolition waste.

1. INTRODUCTION

1.1 Objectives

When rigid pipes are laid in trenches the in-service structural performance of the pipes is dependent on the way in which the trench bottom is regulated. In this context the structural performance of pipes and pipe lines has been improved by using single sized or specifically graded naturally occurring gravels. A detailed investigation to examine the effect of the particle size and shape of naturally occurring aggregates on the settlement and strength of clay pipes was reported in BCRL Technical Note No.150[1].

With increasing difficulties being experienced in obtaining supplies of primary aggregates for bedding pipes, there is a move towards the use of secondary materials. In particular there is a strong interest, fuelled by increasing governmental environmental commitment to recycling, in the use of recycled aggregates produced from crushed demolition waste.

Against this background, the objective of the current project was to determine whether recycled aggregates could be used as an alternative bedding material for drainage installations.

1.2 Work Programme

The project has been monitored and steered by the CERAM Building Technology Clay Pipe Research Committee. In addition to CBT Technical Staff, its constitution includes representatives of all the UK clay pipe manufacturers and of the Clay Pipe Development Association. The committee steerage has resulted in the original outline proposal being developed through four logically progressive phases which can be summarised as:

i) Setting up a test facility to the design of the test rig used to carry out the settlement and strength investigation reported in Technical Note No.150[1].

ii) Validating the test facility by carrying out replicate tests on beddings comprising different gradings of naturally occurring gravel aggregate;

iii) Evaluating the relative performance of selected recycled aggregates supplied in gradings similar to those of the naturally occurring aggregate. This stage of the work was widened to include tests to measure the effect of side loading on displacement and strength.

iv) Determining the performance of more generally available, less selective aggregates defined as demolition waste.

2. MATERIALS

2.1 Pipes

The work to validate the test facility was carried out on batches of DN100 and DN150 pipe sections. For comparison with the earlier work, the plain ended pipes were cut into 915mm (3 foot) lengths by trimming the pipes at both ends. The subsequent work to evaluate the performance of the pipes loaded on recycled aggregate bedding was confined to similarly sized sections cut from two further batches of the same classification of DN15O pipes manufactured by the same company.

In order to determine the baseline strength data necessary to calculate the load ratios of pipe sections tested during the bedding trials, ten sections were randomly selected from successive batches and strength tested. The pipe sections were preconditioned by immersing them in water for times in excess of the minimum periods specified in BS EN 295 : Part 3 : Section 4.1.1 and were tested for crushing strength using the rigid bearer system specified in Section 4.3.3 of the Standard[2]. The ranges, means and statistical variations of the crushing load results are given in Table 1.

TABLE 1 Crushing Loads (BS EN 295 : Part 3 : Section 4)

Pipe Section		Crushing Load		
Type	**Batch**	**Range (kN)**	**Mean (kN)**	**Coefficient of Variation %**
DN100	1	34.4 - 44.7	40.15	9.1
DN150	1	38.6 - 48.2	42.26	7.2
DN150	2	48.2 - 58.3	53.11	5.8
DN150	3	49.2 - 59.7	53.18	6.3

2.2 Naturally Occurring Aggregates

In order to validate the equipment and test procedure against the work reported in Technical Note 150[1], two samples of naturally occurring granular aggregate were obtained from a builders merchant. The gravels were single sized, graded as 10mm and 20mm (G1 and G2).

2.3 Recycled Aggregates

A total of nine recycled aggregates, designated R3-R11, were investigated during the course of the project. These were loosely separated into two groups referred to in the document as “selected recycled aggregates” (R3-R7) and “general demolition waste” (R8-R11). The only difference between the two types of aggregate was that the “selected” materials had been purposely provided whereas the “demolition waste” was collected from sites active at the time of the project. Within the “selected” grouping, aggregates R3 and R4 were supplied from the same source but were separately graded as 20mm down and 20mm to 10mm respectively. The remaining recycled aggregates were supplied as nominal 20mm down gradings. The individual aggregate gradings, together with brief descriptions of their composition, are given in Table 2. The table also includes the gradings of the two naturally occurring aggregates (G1 and G2) and compaction fractions determined on the, as received, natural aggregates and on seven of the recycled aggregates.

TABLE 2 Aggregate Descriptions

Aggregate	Description	Grading	Compaction Fraction
G1	Naturally occurring gravel	Single sized - 10mm	0.15
G2	Naturally occurring gravel	Single sized - 20mm	0.12
R3	The bulk of the aggregate comprised gravel, mortar and stone plus lesser proportions of brick, pottery and glass. The mortar provided the finer fraction	20mm down	-
R4	The same composition as R3 but without the finer, mainly mortar fraction	20mm to 10mm	-
R5	The aggregate consisted of approximately equal proportions of brick, concrete and mortar with the mortar providing the fine fraction	20mm down	0.31
R6	This aggregate was mainly concrete waste plus an insignificant amount of broken brick	20mm down	0.21
R7	The largely concrete aggregate included material noticeably coarser than the 20mm specification. Small amounts of brick, mortar and stone were present	20mm down	0.27
R8	The aggregate was mainly comprised of mortar with small quantities of stone and brick	20mm down	0.30
R9	The aggregate contained similar proportions of gravel, mortar and stone with individual grains larger than 20mm. The mortar contributed the finer fraction	20mm down	0.24
R10	The aggregate comprised nominally equal amounts of ground brick, mortar and stone	20mm down	0.23
R11	The aggregate consisted largely of broken brick plus mortar fines. Small quantities of stone, glass and pottery were also present	20mm down	0.31

3. TEST FACILITY

3.1 Fabrication of the Test Rig

The reinforced box containing the bedding materials, and the smaller boxes used to apply loads to the DN100 and DN150 pipe sections, were designed to replicate the apparatus used for the original work to determine the settlement and strength characteristics of clay pipes tested on single sized granular beds. A schematic diagram showing a pipe positioned on the bedding cradle is shown in Figure 1. Essentially the reinforced wooden box, of internal dimensions 1220mm wide x 990mm long x 305mm deep, and the associated support and loading structure was rigidly constructed to eliminate any deformation movement that could affect the actual displacement occurring within the bed itself. The bedding trials carried out on the DN100 and DN150 pipe sections used an effective box width of 760mm. This was maintained by leaving the packing pieces, illustrated in Figure 1, in place throughout the investigation.

Loading was effected using two separate box type rigs constructed to accommodate the differently sized pipe sections. The rigs, illustrated in Figure 2, consisted of a wooden frame fitted on the underside with a sheet of 14s gauge stainless steel wire mesh of such a width as to ensure a large arc of contact between the mesh and the pipe. The boxes were strengthened by incorporating steel spacer bars across the ends of the boxes.

A photograph of a test in progress in shown in Figure 3.

Proving trials on pipe sections of both diameters, tested on a single sized 10mm gravel bed resulted in the failure of both loading boxes. Damage occurred towards the bottom of the sides of the boxes as the sides were progressively pulled together by the increasing mesh loading. The problem was greater than that experienced in the original work due to the higher inherent strength of the pipes.

Following several unsuccessful attempts to strengthen the boxes, and ongoing discussion within the steering committee, the loading box for the DN150 sections was modified by:

i) Attaching metal bands to further reinforce the box
ii) Using a double layer of the steel mesh; and
iii) By reducing the effective arc of contact between mesh and the apex of the pipe to approximately 90˚.

As a result of the extensive work required to modify the box for the DN150 pipes, it was decided to construct an all steel loading box for the DN100 pipes. The new box incorporated a double layer of the steel mesh, again installed to provide a 90˚ arc of contact between the mesh and the pipe.

Figure 1 Apparatus for Bedding and Side Fill Loading

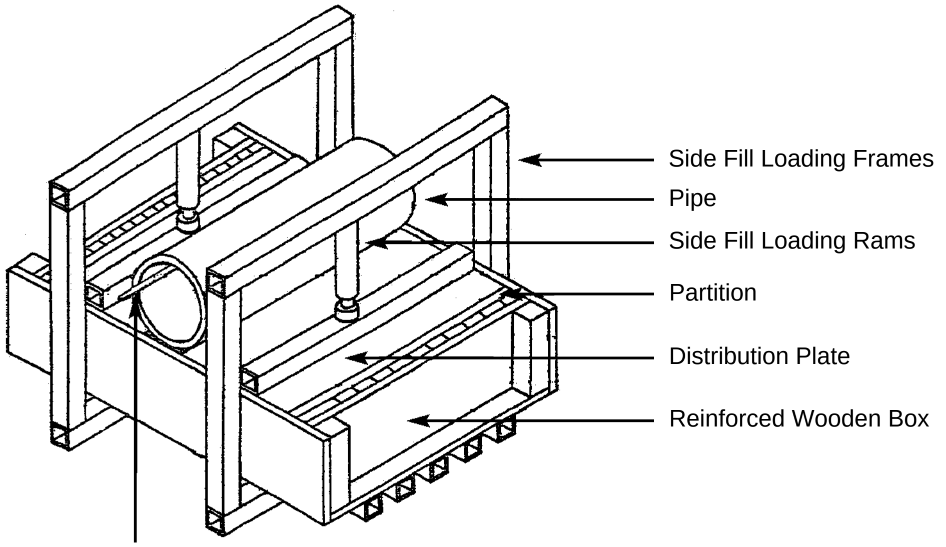


Figure 2 Pipe Loading Arrangement

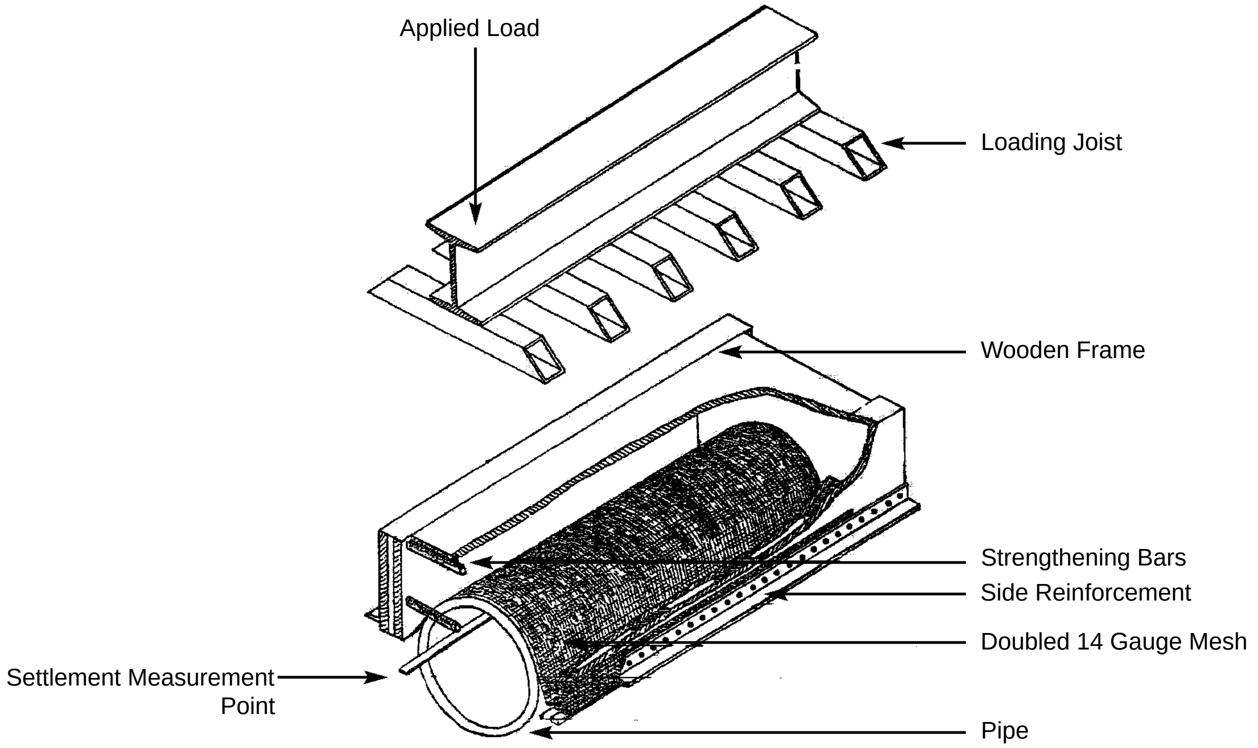
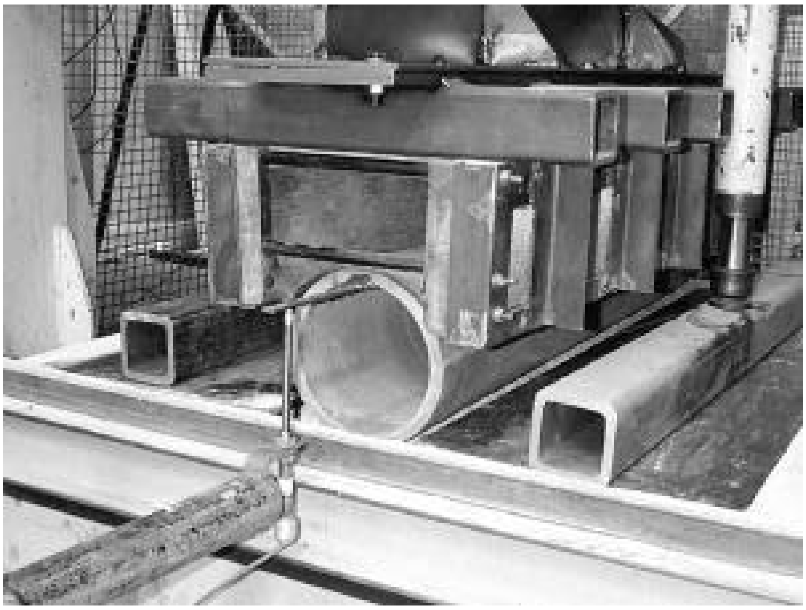


Figure 3 Photograph of Pipe Testing Apparatus



3.2 Proving Trials on Naturally Occurring Aggregate Bedding

The testing procedure used for carrying out the trials on the naturally occurring aggregate beds was adopted throughout the investigation. The reinforced box was filled to a depth of 150mm with bricks and covered with several layers of strawboard. The remaining 150mm deep bed was filled with the prescribed aggregate. The materials were shovelled and sliced into the bed and were finally levelled by hand. Importantly there was no pre-test compaction.

In order to obtain an accurate load ratio between the proof strengths and bedded strengths, the pipe sections tested on the natural aggregate bedding were soaked in water for periods in excess of those specified in BS EN 295. The same preconditioning procedure was subsequently used for the sections tested on the recycled aggregate beds.

The side load distribution plates were placed onto the bed, positioned far enough apart to allow for unimpaired pipe settlement but not wide enough for aggregate to be squeezed from between the pipe and plates during loading. The pipe section was laid horizontally onto the bed in line with the loading rig and the designated loading box was placed squarely on top of the pipe. With the side loading frames located on the distribution plates and the loading rig lowered onto the pipe preparations were complete for the start of the test.

The tests on pipe sections placed on the natural aggregate bed were carried out using the test parameters employed in the earlier investigation. A load of 15kN was supplied to the side plates whilst the pipes themselves were loaded to failure at a constant rate of 450N/sec. The displacement occurring during loading was monitored at both ends of the pipe using transducers located against plates secured to the top internal surface of the pipes. Use of data logging facilities enabled a continuous record of displacement to be obtained up to the ultimate point of pipe failure. The average displacement determined from the readings taken at the two ends of the pipe was noted for the previously standardised settlement load of 22kN and at the failure load. For each pipe type and gravel grading test condition, five replicate tests were carried out. Between successive tests the same bedding material was retained but was dug out and reconstituted.

The average displacements and failure loads measured on the DN150 pipes tested on the 10mm and 20mm single sized naturally occurring gravel beds are given in Tables 3 and 4 respectively, whilst Tables 5 and 6 give the equivalent results for the DN100 pipe sections. In the tables the displacements quoted during the tests equate to the differences between the displacements measured at the settlement load (22kN) and immediately prior to fracture. The load ratio is the failure load divided by the batch mean determined on the proof tested sections.

TABLE 3 DN150 Pipes Tested on 10mm Granular Gravel Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	0.98	3.92	2.94	56.1	1.33
2	2.48	6.29	3.81	64.7	1.53
3	2.41	4.88	2.47	52.1	1.23
4	2.41	6.88	4.47	67.1	1.59
5	2.07	4.76	2.69	53.8	1.27
Mean	**2.07**	**5.35**	**3.28**	**58.8**	**1.39**

TABLE 4 DN150 Pipes Tested on 20mm Granular Gravel Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	2.67	6.53	3.86	60.6	1.43
2	2.09	5.10	3.01	40.4	0.96
3	1.89	5.36	3.47	60.4	1.43
4	1.39	4.93	3.54	66.4	1.57
5	2.47	5.71	3.24	51.6	1.22
Mean	**2.10**	**5.53**	**3.42**	**55.9**	**1.32**

TABLE 5 DN100 Pipes Tested on 10mm Granular Gravel Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	3.78	7.18	3.40	40.01	1.00
2	2.81	8.01	5.20	60.52	1.51
3	3.57	7.29	3.72	45.87	1.14
4	2.83	5.63	2.80	42.94	1.07
5	2.55	6.84	4.29	51.64	1.29
Mean	**3.11**	**6.99**	**3.88**	**48.20**	**1.20**

TABLE 6 DN100 Pipes Tested on 20mm Granular Gravel Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	1.40	4.33	2.93	52.46	1.31
2	2.81	7.32	4.51	47.93	1.19
3	2.12	5.78	3.66	52.46	1.31
4	2.03	5.49	3.46	53.19	1.32
5	1.51	4.12	2.61	50.22	1.25
Mean	**1.97**	**5.41**	**3.43**	**51.25**	**1.28**

4. TRIALS USING RECYCLED AGGREGATE

4.1 Selected Aggregates

In order to assess the relative performance of naturally occurring and recycled aggregates initial bedding trials concentrated on measuring the displacement and strength of DN100 and DN150 pipe sections on two gradings of a single sourced aggregate. The aggregates, supplied as separate 20mm down and 20-10mm gradings, are identified as R3 and R4 respectively in Table 2. Using the side load, loading rate and settlement load applied during the tests on the granular gravel beddings, series of five tests were carried out to determine the displacements and strengths of DN100 and DN150 pipes on beds comprising both recycled aggregate gradings. The results obtained for the DN150 pipe sections are reported in Tables 7 and 8 and for the DN100 specimens in Tables 9 and 10.

TABLE 7 DN150 Pipes Tested on 20mm Down Recycled Aggregate (R3) Bed

Pipe Section	Side Load (kN)	Displacement (mm)			Failure Load kN	Load Ratio
		At Settlement Load	At Failure Load	During Test		
A	7.5	21.03	37.83	16.80	80.96	1.92
B	7.5	20.48	34.36	13.88	66.33	1.57
	Mean	**20.76**	**36.10**	**15.34**	**73.65**	**1.74**
1	15	24.79	37.16	12.37	63.17	1.49
2	15	23.40	35.93	12.54	65.77	1.56
3	15	21.42	32.71	11.29	60.52	1.43
4	15	19.43	26.19	6.76	46.60	1.10
5	15	19.67	32.44	12.77	70.77	1.67
	Mean	**21.74**	**32.89**	**11.15**	**61.37**	**1.45**
C	30	13.71	26.18	12.47	70.04	1.66
D	30	14.44	24.48	10.04	57.59	1.36
	Mean	**14.08**	**25.33**	**11.26**	**63.82**	**1.51**
E	40	10.09	21.98	11.89	60.01	1.42

TABLE 8 DN150 Pipes Tested on 20mm to 10mm Recycled Aggregate (R4) Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	19.33	37.39	18.06	68.57	1.62
2	15.88	32.51	16.63	65.64	1.55
3	14.32	30.13	15.81	67.11	1.59
4	17.94	31.04	13.11	55.99	1.32
5	16.77	29.14	12.37	54.66	1.29
Mean	**16.85**	**32.04**	**15.20**	**62.39**	**1.48**

TABLE 9 DN100 Pipes Tested on 20mm Down Recycled Aggregate (R3) Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	26.17	39.91	13.74	64.18	1.60
2	22.13	38.93	16.80	76.59	1.91
3	21.56	34.86	13.30	61.98	1.54
4	20.95	32.39	11.44	58.32	1.45
5	22.33	34.55	12.22	60.47	1.51
Mean	**22.63**	**36.13**	**13.50**	**64.31**	**1.60**

TABLE 10 DN100 Pipes Tested on 20mm to 10mm Recycled Aggregate (R4) Bed

Pipe Number	Displacement (mm)			Failure Load kN	Load Ratio
	At Settlement Load	At Failure Load	During Test		
1	13.98	32.25	18.27	70.77	1.76
2	18.58	33.41	14.83	58.73	1.46
3	17.33	33.82	16.49	67.11	1.67
4	18.50	33.63	15.13	59.05	1.47
5	16.62	33.76	17.14	69.31	1.73
Mean	**17.00**	**33.37**	**16.37**	**64.99**	**1.62**

When the results given in Tables 7-10 were compared with those obtained on the similarly sized natural aggregate bedding, it was apparent that considerably higher displacements occurred with the recycled material. To investigate whether the displacement would be affected by variations in the side load, exploratory tests were carried out using the remaining DN150 pipes tested on a 20mm down recycled aggregate bed. The limited numbers of tests carried out using side loads of 7.5, 30 and 40kN have been included in Table 7 alongside the results obtained using the standardised (15kN) side load.

Although the results did suggest that both displacement and strength were affected by the side fill loading, the inherent variations between the sections tested using the different additional side load regimes rendered the findings inconclusive. Consequently, to investigate the influence of side loading more fully, the steering group agreed to extend the work to include tests on a further three recycled aggregates. The additional work would also quantify any difference in the performance of differently sourced recycled aggregates.

The extended investigation was confined to a fresh batch of DN150 pipe sections (Batch 2) which were tested on single, 20mm down gradings, of the three additional aggregates (R5, R6 and R7). The results of strength tests carried out on ten randomly selected sections, preconditioned and tested using the procedures in BS EN 295, are included in Table 1. Details of the aggregate compositions are given in Table 2 together with compaction fractions determined on the as received materials. The compaction fractions were determined using the method given in Appendix A of the report of the working party into the design and construction of under ground pipe sewers[3].

Using the established loading rate (450N/sec) pairs of tests were carried out using the 15kN side load. In addition a minimum of four tests were carried out at increased applied side loads of both 30 and 45kN. The results obtained using beds comprising aggregates R5, R6 and R7 are given in Tables 11,12 and 13 respectively.

TABLE 11 DN150 (Batch 2) Pipes Tested on 20mm Down Aggregate (R5) Bed

Pipe Section	Side Load (kN)	Displacement (mm)			Failure Load kN	Load Ratio
		At Settlement Load	At Failure Load	During Test		
1	15	22.99	40.00	17.01	89.86	1.69
2	15	22.20	40.02	17.82	93.39	1.76
	Mean	**22.60**	**40.01**	**17.42**	**91.63**	**1.73**
3	30	18.79	35.13	16.34	85.28	1.61
4	30	19.29	35.01	15.72	87.85	1.65
5	30	19.04	34.76	15.72	87.65	1.65
6	30	16.70	32.90	16.20	95.40	1.80
7	30	20.86	36.81	15.95	98.79	1.86
	Mean	**18.94**	**34.92**	**15.98**	**90.99**	**1.71**
8	45	19.22	33.42	14.20	80.61	1.52
9	45	18.49	30.12	11.62	73.38	1.38
10	45	17.54	32.66	15.12	96.82	1.82
11	45	18.17	33.90	15.73	92.79	1.75
12	45	15.16	28.91	13.75	84.55	1.59
	Mean	**17.72**	**31.80**	**14.08**	**85.63**	**1.61**

TABLE 12 DN150 (Batch 2) Pipes Tested on 20mm Down Recycled Aggregate (R6) Bed

Pipe Section	Side Load (kN)	Displacement (mm)			Failure Load (kN)	Load Ratio
		At Settlement Load	At Failure Load	During Test		
1	15	16.07	31.53	15.46	79.61	1.50
2	15	13.85	30.17	16.33	92.70	1.75
	Mean	**14.96**	**30.85**	**15.89**	**86.16**	**1.62**
3	30	12.67	25.26	12.60	76.13	1.43
4	30	12.55	24.32	11.77	75.30	1.42
5	30	10.51	22.06	11.51	78.37	1.47
6	30	10.09	21.32	11.23	77.50	1.46
7	30	11.22	24.38	13.16	87.30	1.64
	Mean	**11.41**	**23.46**	**12.05**	**78.92**	**1.49**
8	45	9.84	20.53	10.69	77.41	1.46
9	45	8.85	19.29	10.45	76.91	1.45
10	45	8.82	18.70	9.88	71.64	1.35
11	45	10.56	21.81	11.26	79.84	1.50
	Mean	**9.52**	**20.08**	**10.57**	**76.45**	**1.44**

TABLE 13 DN150 (Batch 2) Pipes Tested on 20mm Down Recycled Aggregate (R7) Bed

Pipe Section	Side Load (kN)	Displacement (mm)			Failure Load (kN)	Load Ratio
		At Settlement Load	At Failure Load	During Test		
1	15	24.43	41.16	16.73	67.89	1.28
2	15	20.40	36.89	16.49	76.08	1.43
	Mean	**22.42**	**39.03**	**16.61**	**71.99**	**1.36**
3	30	17.46	27.89	10.43	54.34	1.02
4	30	13.69	27.81	14.12	77.91	1.46
5	30	14.07	30.80	16.73	88.08	1.66
6	30	15.05	28.33	13.29	68.53	1.29
7	30	14.14	24.46	10.32	55.16	1.04
	Mean	**14.88**	**27.86**	**12.98**	**68.80**	**1.30**
8	45	12.87	20.23	7.36	47.79	0.90
9	45	10.77	24.41	13.65	74.16	1.40
10	45	9.95	20.75	10.80	67.52	1.27
11	45	11.35	19.36	8.01	48.48	0.91
	Mean	**11.23**	**21.19**	**9.95**	**59.49**	**1.12**

The technique of removing the aggregate from the box following each individual test and of reconstituting the bed using the same material, established during the work on the granular gravel bedding, continued to be used for the tests using the selected recycled aggregates. Consequently each series of tests involving different pipe sizes and aggregate batches was conducted using the same sample of aggregate.

To determine the affect of the progressive test work on the aggregates themselves, sieve analyses were determined on representative samples of both the aggregate as received and following the bedding trials. The comparative sieve analyses determined on each of the selected recycled aggregates (R3-R7) are given in Table A1 of Appendix A of the report.

4.2 General Demolition Waste

To address concerns as to whether the selected recycled aggregates provided a fair representation of the more readily available demolition waste it was decided to further extend the investigation to include aggregates from currently active demolition sites. Specified 20mm down gradings were either collected from or supplied by contractors operating sites where demolition waste was being processed. Details of the composition of the aggregates (R8-R11) and compaction fractions determined on representative samples of the as received materials have been included in Table 2 alongside the data for the remaining aggregates.

To facilitate the additional test work, a third batch of DN150 915mm long sections were provided from the same source and with the same specifications as those supplied for Batches 1 and 2. Proof strengths determined on ten randomly selected sections are given in Table 1. Displacement and strength measurements were determined on beds prepared from each aggregate using the standard loading rate of 450N/sec and with a single side load of 45kN. Five replicate determinations were carried out on bedding comprising each of the demolition wastes. The displacements measured at the settlement load (22kN) and at failure, together with the failure loads and calculated load ratios, determined on pipe sections tested on each of the four aggregate beds are compared in Table 14.

TABLE 14 Bedding Trials Using Demolition Waste

Aggregate	Section Number	Displacement (mm)			Failure Load (kN)	Load Ratio
		At Settlement Load	At Failure Load	During Test		
R8	1	21.46	39.56	18.10	99.29	1.87
	2	21.08	37.95	16.87	94.03	1.77
	3	20.08	37.88	17.81	99.34	1.87
	4	22.25	37.03	14.78	92.93	1.75
	5	21.68	38.27	16.59	93.66	1.76
	Mean	**21.31**	**38.14**	**16.83**	**95.85**	**1.80**
R9	1	18.26	30.95	12.69	83.54	1.57
	2	15.24	29.62	14.38	84.46	1.59
	3	16.83	30.13	13.30	79.01	1.49
	4	13.17	27.70	14.53	92.52	1.74
	5	16.31	29.03	12.72	75.30	1.42
	Mean	**15.96**	**29.49**	**13.53**	**82.97**	**1.56**
R10	1	17.69	33.84	16.15	93.61	1.76
	2	10.72	25.73	15.01	90.59	1.70
	3	11.32	23.61	12.29	72.01	1.35
	4	11.86	29.21	17.35	102.95	1.94
	5	12.52	27.86	15.34	89.77	1.69
	Mean	**12.82**	**28.05**	**15.23**	**89.79**	**1.69**
R11	1	19.81	37.52	17.71	90.59	1.70
	2	17.40	28.95	11.55	82.03	1.54
	3	16.73	33.79	17.06	93.11	1.75
	4	20.42	36.74	16.32	92.56	1.74
	5	19.22	35.81	16.59	94.85	1.78
	Mean	**18.72**	**34.56**	**15.84**	**90.63**	**1.70**

To determine whether, and to what extent, the aggregates themselves had been affected by their use as bedding materials, sieve analyses were carried out on the aggregates prior to and following each series of tests. The results of the analyses are given in Table A2 of Appendix A.

5. SUMMARY

The work carried out during the first stage of the project involved constructing a test facility to replicate that used in the 1960's to investigate the settlement and strength of clay pipes tested on single-size granular cradles. Teething problems in fabricating the separate loading boxes for testing the DN100 and DN150 pipe sections were caused by the higher strengths of the pipes used in the current investigation.

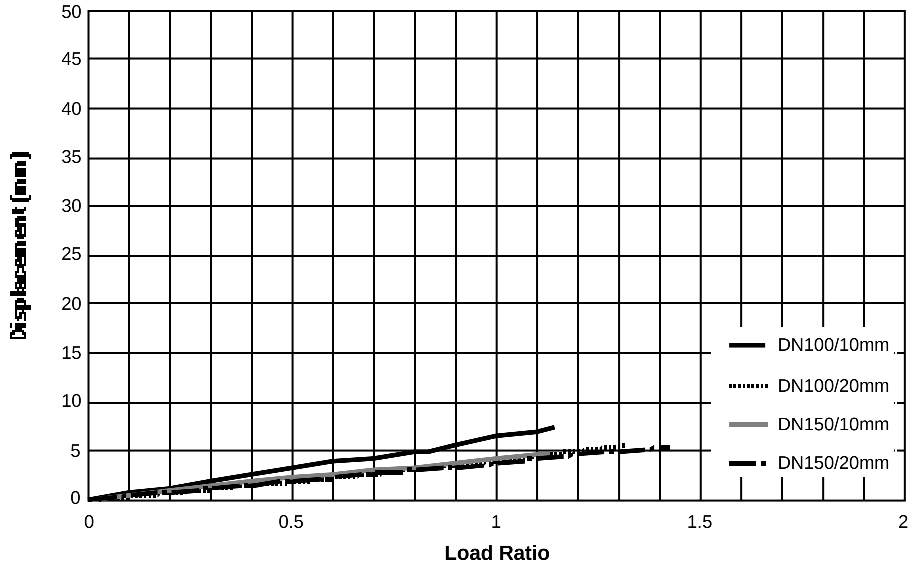
The validation work, which involved testing DN100 and DN150 sections on single-sized 10mm and 20mm naturally occurring granular aggregate beds, showed good agreement with the results of the earlier work. Table 15 gives the settlement displacements and load ratios determined during the current work and the comparative historical data reported in Technical Note No.150[1].

TABLE 15 Comparative Data - Pipes Tested on Natural Aggregate Beds

Pipe Size	Gravel Grading (mm)	Results - TN150			Results - Current Project		
		Settlement Displacement (mm)	Failure Load (kN)	Load Ratio	Settlement Displacement (mm)	Failure Load (kN)	Load Ratio
DN100	10	3.4	50.7	1.58	3.1	48.2	1.20
DN100	20	3.6	ND	ND	2.0	51.3	1.28
DN150	10	4.8	42.7	1.47	2.1	58.8	1.39
DN150	20	3.2	41.8	1.43	2.1	55.9	1.32

Graphs showing the relationship between displacement and load ratio for each pipe/bedding condition are shown in Figure 4. The data used to construct the curves is that continuously generated from single sections having results closest to the batch means.

FIGURE 4 Load Ratio / Displacement Relationship. Pipes tested on natural Aggregate Bedding



The crushing loads determined on the DN100 (4 in) and DN150 (6 in) sections reported in TN150[1] were 32.4kN and 29.1kN respectively, compared with the 40.2kN and 42.3kN determined on the batches of DN100 and DN150 used in the proving trials.

The differences in the settlement displacements and load ratios illustrated in the table reflect the modifications to the loading boxes in particular the mesh adjustment which reduced the arc of contact at the apex of the pipes to approximately 90˚. Certainly the displacement differences between the comparative earlier and current work are small when compared with the subsequent measurements on the recycled aggregate bedding.

The initial work on the recycled aggregates, using two gradings of nominally 20mm down (R3) and 20-10mm (R4) of the same aggregate, immediately showed a dramatic, almost tenfold, increase in the displacement measured at the settlement load. For both the DN100 and DN150 pipe sections lower displacements were measured during the tests carried out on the 20-10mm material. However, at the point immediately prior to failure, this difference had been redressed so that tests carried out on both grades of aggregate showed similar overall displacements and load ratios. Higher overall displacements and load ratios were measured for the DN100 sections.

The extended programme of work, involving testing DN150 pipe sections on aggregate R3 and three other differently sourced 20mm down recycled aggregate beddings, illustrated that variations in performance, both in terms of displacement and load ratio, could be expected. The work also confirmed that even the lowest settlement and failure load displacements represented an approximate sixfold increase when compared with the results of the tests carried out on naturally occurring aggregate.

Initial work to determine the influence of the side plate loads on displacement using aggregate R3 showed that the settlement and failure displacements were only slightly affected by halving the standardised 15kN side load. However, when the side load was doubled to 30kN a marked decrease in displacement occurred. Subsequent tests on the additional three selected recycled aggregates (R5, 6 and 7), using 15, 30 and 45kN side loads, indicated that the displacements at settlement and failure continued to be reduced as the side load was increased. In all three cases the reductions resulting from increasing the side load from 30kN to 45kN were less than those caused by the 15kN to 30kN increase. This may indicate that a maximum displacement will ultimately be reached where increases in side load have no further effect. In this respect, it is important that side loads applied during laboratory testing fairly represent the conditions that appertain on site.

The relationships between load ratio and progressive displacement are shown graphically in Figures 5 - 8 for recycled aggregates R3, 5, 6 and 7 respectively. Each figure includes a family of curves illustrating the influence of varying the side load. Load ratios rather than failure loads have been used in order to accommodate the different proof strengths of the two batches of DN150 pipe sections (Table 1). As in Figure 4, the load ratio and displacement data used to construct the individual curves in each of the figures are those generated for the single pipe sections with results closest to the batch means. Whilst these do reflect the overall results, the inherent testing variation occurring where only pairs of sections were tested does affect the ultimate accuracy. A direct comparison between the performance of recycled aggregates R5-7 is given in Figure 9. This combines the curves for tests carried out using a 45kN side load extracted from Figures 6-8. Tests on recycled aggregate R3 did not include trials using a 45kN side load.

FIGURE 5 Aggregate R3 - Effect of Side Load on Load Ratio / Displacement Relationship

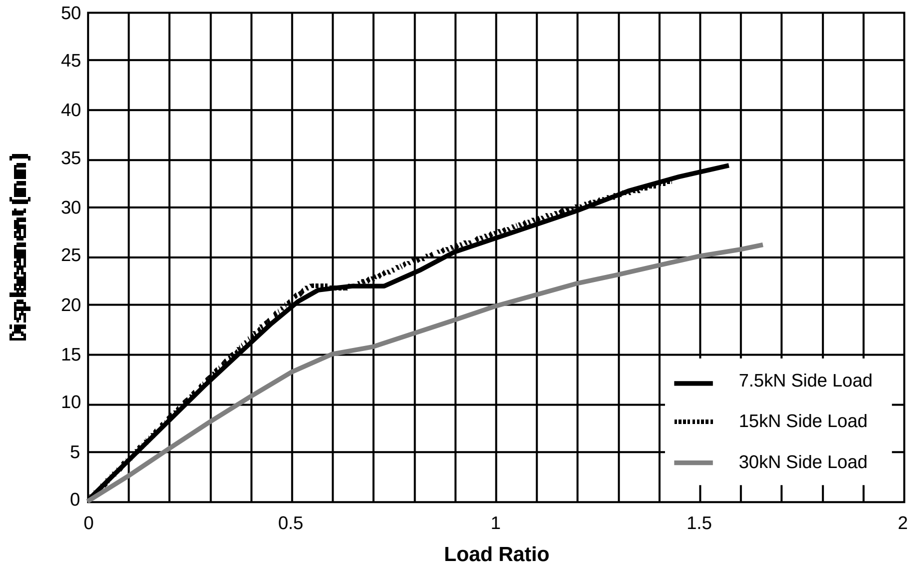


FIGURE 6 Aggregate R5 - Effect of Side Load on Load Ratio / Displacement Relationship

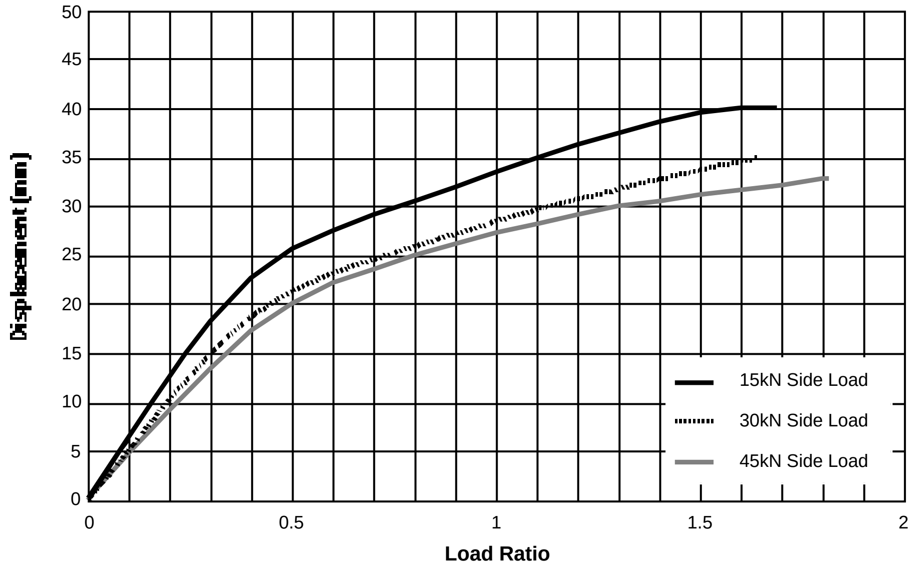
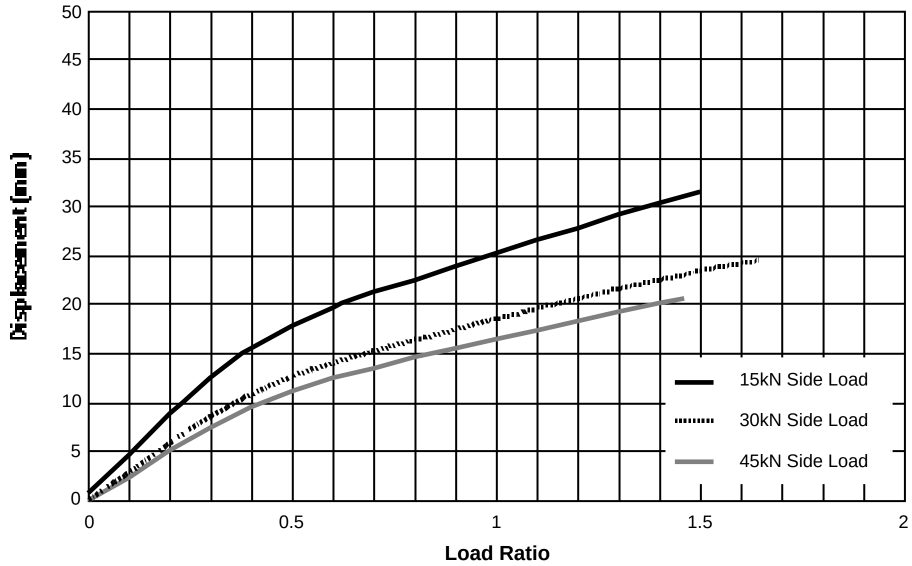


FIGURE 7 Aggregate R6 - Effect of Side Load on Load Ratio / Displacement Relationship



The second series of tests on recycled aggregates used demolition waste which was readily available and consequently was more likely to be used in practice. DN150 pipe sections were tested on bedding prepared from four aggregates from different active demolition sites provided as specified 20mm down gradings. Load ratio/displacement relationships determined using a single side loading regime of 45kN are shown in Figure 10. In the figure the lines relate to the continuous displacement curves obtained for those single determinations which most closely matched the mean values. When compared with the results for the “selected” aggregates in Figure 9, it is apparent that generally higher settlements and load ratios were obtained with the demolition wastes. Whilst there were variations between the results determined for the four wastes, they all exhibited the same displacement profile.

FIGURE 8 Aggregate R7 - Effect of Side Load on Load Ratio / Displacement Relationship

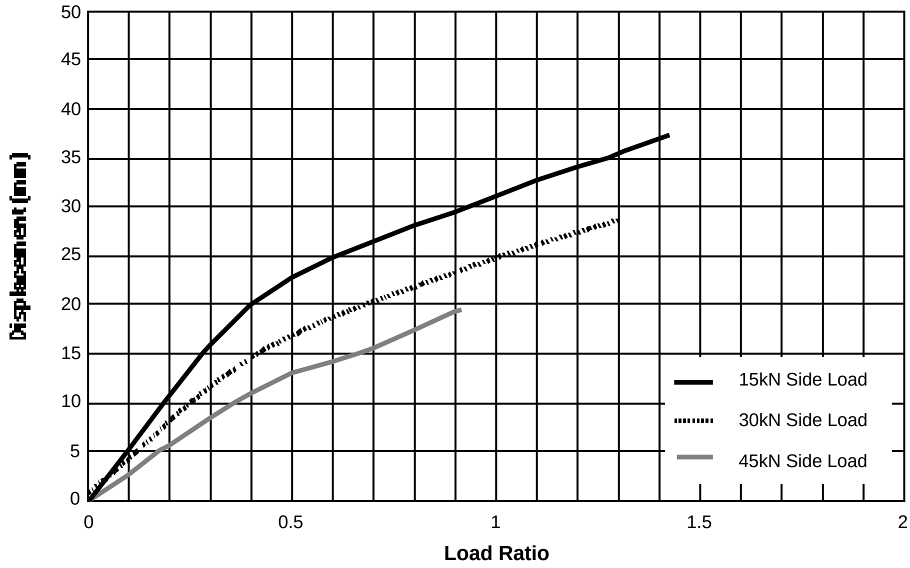


FIGURE 9 Aggregates R5, R6 & R7. Load Ratio / Displacement Relationships using 45kN Side Load

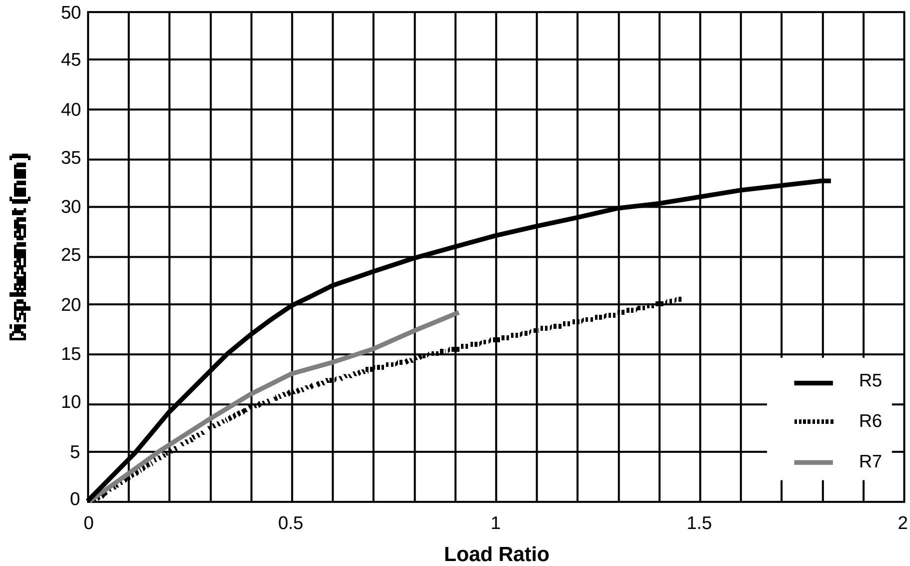


FIGURE 10 Aggregate R8 - R11. Load Ratio / Displacement Relationships using 45kN Side Load

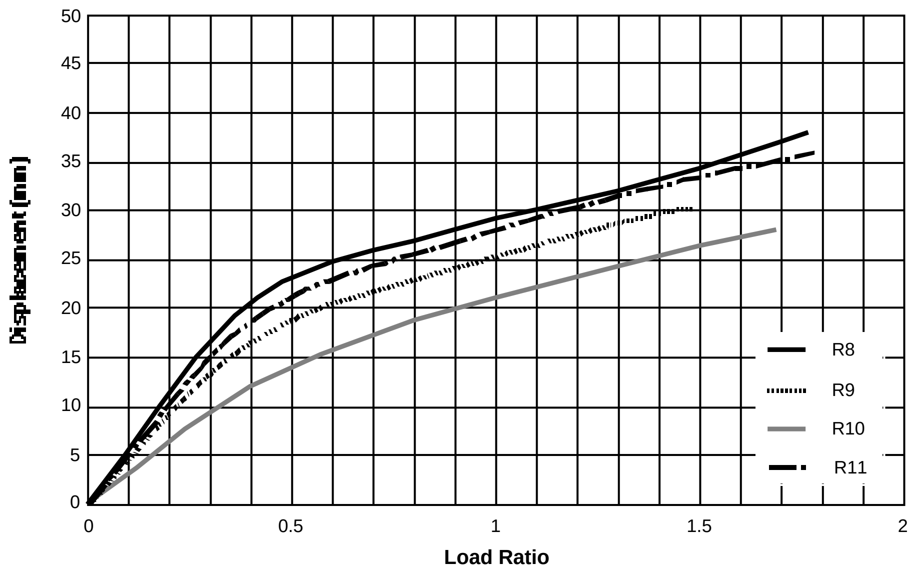


Table 16 provides a numerical comparison between all the recycled aggregates investigated. In the table mean values of the settlement and failure displacements, together with the load ratios, are given for tests carried out on DN150 sections using 15kN and 45kN side loads.

The results in the table, together with the curves in Figures 9 and 10, indicate that the characteristics of the different aggregates have a significant effect on the displacements and load ratios determined using the DN150 pipe sections. The measurements taken where both 15kN and 45kN side loads were applied (aggregates R5, 6 and 7), indicate that there is a direct relationship between displacement and load ratio. Increasing the side load from 15kN to 45kN resulted in lower displacements which reduced the arcs of contact between the pipe and bedding. This in turn increased the stress per unit area and consequently reduced the failure load and load ratio. However it is apparent from the results in the table that a common proportional relationship does not exist between displacement and load ratio, pointing to the influence of the individual aggregates.

TABLE 16 Comparative Displacement and Load Ratio Measurements

	Side Load 15kN			Side Load 45kN		
	Displacement (mm)			Displacement (mm)		
Aggregate	At Settlement	At Failure	Load Ratio	At Settlement	At Failure	Load Ratio
R3	21.74	32.89	1.45	-	-	-
R4	16.85	32.04	1.48	-	-	-
R5	22.60	40.01	1.73	17.72	31.80	1.61
R6	14.96	30.85	1.62	9.52	20.08	1.44
R7	22.42	39.03	1.36	11.23	21.19	1.12
R8	-	-	-	21.31	38.14	1.80
R9	-	-	-	15.96	29.49	1.56
R10	-	-	-	12.82	28.05	1.69
R11	-	-	-	18.72	34.56	1.70

Differences both within and between the groups comprising “selected aggregates” and “demolition wastes” are confirmed by the compositional details and compaction fractions given in Table 2. Further evidence of the grading and friability of the different aggregates is provided by the sieve analyses, carried out on the materials prior to and following each series of bedding trials, reported in Appendix A.

The lowest displacements using both side loads were measured on aggregate R6 which gave the lowest compaction value of 0.21. Interestingly the displacements measured with the lower, 15kN, side load were lower than those determined using the more controlled size grading, 20-10mm, of aggregate R4. The performance of R4 as a more nearly single sized material may have been affected by the aggregate breakdown that occurred during testing, evidenced by the sieve analyses.

The principle relating high compaction fractions to high displacement was also exhibited by the three aggregates having the highest compaction fractions (R5, R8 and R11). These aggregates produced the highest displacements when tested with an applied side load of 45kN. Of these, two of the aggregates suffered breakdown during testing whilst the third, R11, perhaps surprisingly exhibited similar grading and friability properties to R6. The compactibility test, which gave results of 0.21 and 0.31 for R6 and R11 respectively, suggested that the different performance resulted from variations in the composition and angularity of the two materials.

The lowest load ratio for comparable results obtained using both side loading regimes was measured for aggregate R7. The lower strengths resulted from the presence of a significant proportion of oversized concrete lumps which caused localised stress development. This aggregate also produced some of the lowest displacement figures.

It is clear from these attempts to relate displacement and load ratio to aggregate characteristics, that there are a number of factors which will affect the performance, and ultimately choice, of recycled aggregates. These will include the composition, grading - both in terms of size specification and supply - and friability of the aggregates. Probably the best overall guide as to the suitability of a particular aggregate will be the determination of the compaction fraction.

6. CONCLUSIONS

In the somewhat artificial laboratory conditions the project has shown that comparable settlements as high as ten times those measured on single sized naturally occurring aggregate may be obtained when using nominally 20mm down graded recycled aggregate bedding. Limited evidence has shown that the displacement is reduced where a more selective recycled aggregate grading, excluding the finer fraction, is used. However, the effectiveness of single sized material will be affected by its friability since a high degree of friability will lead to breakdown of the aggregate during trench preparation and pipe laying. Such breakdown would widen the size grading and consequently alter the settlement characteristics.

In an on site situation it is probable that the relative displacements measured during the laboratory trials would be reduced by a number of practical factors. The bed compaction occurring during the bed preparation and pipe laying activities, the use of haunching influencing the actual load on the pipes and the side loading applied in situ will all reduce the level of displacement. With respect to the side loading, experimental work has indicated that the 45kN side load used in a number of the tests fairly reflects the in service situation. The design loadings for trenches with depths of up to 6 metres for a main road situation are shown in Figure 11. The figure shows both the total loading and the contribution due to backfilling. From the figure it is apparent that the maximum load equating to a 6m deep trench is approximately 37kN. Consequently, whilst the failure loads determined during the laboratory tests do reflect the load likely to result in pipe failure, the average crushing load of 83kN, determined on pipes tested on beddings comprising the seven recycled aggregates tested using a side load of 45kN, is much higher than the value calculated for an on site situation. The lower practical loading will naturally result in a lower comparative displacement. Figure 11 includes a graphical relationship between the loads defined by the different site trench depths and the corresponding average displacements extrapolated from the laboratory investigation.

The compaction fraction is a well-established method used on-site as a guide to the suitability of materials for pipe bedding. Essentially the test determines the need for compaction of materials to enable them to support loads. Whilst the basic reference data, including the test method, are given in the HMSO Working Party Report[3] published in 1967, the values have been perpetuated in the more recent WAA Specification No. 4-08-22[4] for pipe bedding materials. Under the guidelines a maximum compaction fraction of 0.3 is accepted as a benchmark for Class N bedding. Class N bedding is defined as a flat bed comprising a wide range of granular materials which will give uniform support to a pipe having a minimum bedding factor (load ratio) of 1.1.

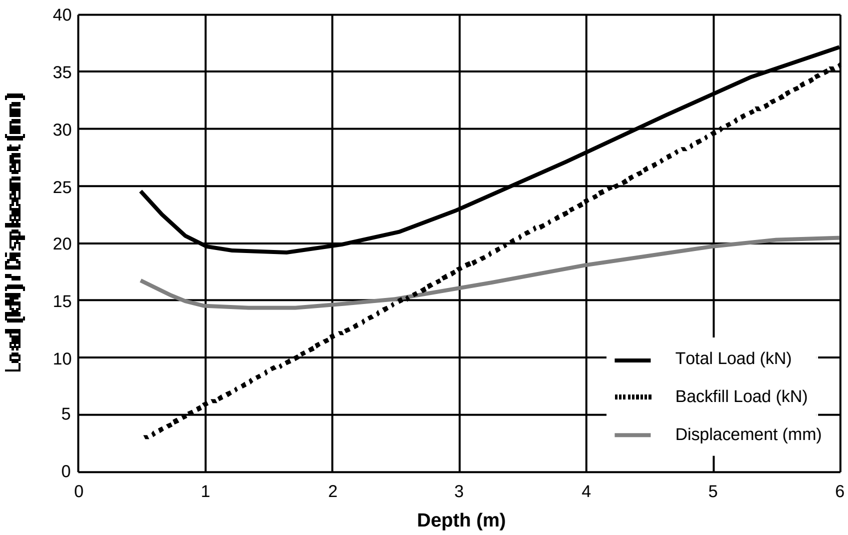
In the project the compaction fractions measured on seven of the recycled aggregates ranged from 0.21 to 0.31, three giving values equal to or just exceeding the 0.30 limit. Equivalent measurements on the 10mm and 20mm gravels were 0.15 and 0.12 respectively.

The comparison between the properties of the “selected aggregates” and “demolition wastes” has illustrated the need for careful specification and verification of the recycled aggregates. In determining the specification, care is required over the composition, grading and friability of the materials. If these are controlled the aggregate is more likely to fall below the compaction fraction limit of 0.3.

Evidence from the tests carried out using a 45kN side load demonstrates that the majority of aggregates would achieve load ratios (bedding factors) in excess of the 1.1 minimum. Only aggregate R7, with a load ratio of 1.12 approached this limit. Here the performance of the aggregate was affected by the presence of a significant proportion of oversized hard angular pieces of concrete. Such oversized material would be expected to be excluded when aggregates are supplied to a stated specification.

Using bedding material derived from recycled construction and demolition waste, the tests have indicated the achievement of satisfactory load ratios with acceptable displacements at loads to be expected in practice .

FIGURE 11 Design Loading and Displacement Relationships for DN150 Pipes Laid on 20mm Down Recycled Aggregate Bedding



ACKNOWLEDGMENTS

The authors would like to thank the UK Clay Pipe Industry and those contractors who supplied the range of bedding materials for their support during the investigation. Thanks are also expressed to Mr D. Morrey for his help in fabricating the test rig and in carrying out the subsequent test work.

REFERENCES

1. Picken, R.N., The Settlement and Strength of Clay Pipes on Single-size Granular Cradles. B Ceram R.A. Tech. Note 150,1969.

2. British Standard. Vitrified Clay Pipes and Fittings and Pipe Joints for Drains and Sewers. Part 3. Test Methods. BS EN 295: Part 3:1991.

3. Ministry of Housing and Local Government. Working Party on the Design and Construction of Underground Pipe Sewers. H.M.S.O. 1967.

4. Specification for Pipe Bedding Materials No.4-08-22 WAA 1994.

APPENDIX A

SIEVE ANALYSES ON RECYCLED AGGREGATES

TABLE A1 Sieve Analyses - "Selected" Recycled Aggregates

Mesh Size (mm)	Cumulative Percentage Retained									
	R3		R4		R5		R6		R7	
	As Received	Following Testing	As Received	Following Testing	As Received	Following Testing	As Received	Following Testing	As Received	Following Testing
20.0	2.5	0.9	2.8	0	0.9	1.2	0	0	25.3	19.3
14.0	14.3	7.7	18.1	7.9	2.8	4.4	8.7	5.1	37.9	32.2
10.0	33.8	21.9	39.5	26.6	10.8	10.7	20.1	14.6	49.2	40.6
6.3	52.4	38.5	70.1	55.3	20.1	21.9	32.0	24.1	58.4	49.4
5.0	57.4	43.7	77.9	63.7	27.4	30.6	40.8	32.2	64.2	55.9
3.35	62.2	49.4	84.7	71.5	35.0	38.4	48.6	39.8	69.3	61.5
2.36	65.2	53.5	87.2	74.6	43.5	45.8	56.6	47.6	73.6	67.4
1.18	70.9	60.5	88.9	78.0	60.1	58.5	70.6	62.4	80.2	77.6
0.60	77.1	68.0	90.2	81.2	67.6	69.5	79.4	71.7	85.0	84.9
0.30	87.0	80.6	92.9	87.4	86.4	84.4	86.9	81.5	89.9	90.8
0.212	92.2	88.0	95.0	91.6	92.5	90.1	90.2	86.1	92.5	93.2
0.150	95.3	93.0	96.6	94.6	95.4	93.6	92.4	89.2	94.6	94.7
0.075	98.1	97.8	98.2	97.9	98.7	98.0	96.6	95.4	97.8	97.5
<0.075	1.9	2.2	1.8	2.1	1.3	2.0	3.4	4.6	2.2	2.5

* Material graded as 20 - 10mm

TABLE A2 Sieve Analyses - Demolition Wastes

Mesh Size (mm)	Cumulative Percentage Retained							
	R8		R9		R10		R11	
	As Received	Following Testing	As Received	Following Testing	As Received	Following Testing	As Received	Following Testing
20.0	0	0.1	31.7	12.6 †	0	0	0	0
14.0	0.3	0.1	37.9	17.2	5.2	6.4	3.6	3.3
10.0	1.6	2.6	49.2	24.9	17.4	18.7	18.4	14.4
6.3	8.4	10.7	62.4	38.1	32.4	33.6	35.3	27.9
5.0	15.6	18.1	69.2	47.7	43.4	44.7	45.4	37.0
3.35	29.6	25.9	73.8	55.9	53.1	53.9	52.4	44.6
2.36	37.8	48.5	77.7	63.8	61.2	61.7	58.0	51.2
1.18	59.4	59.0	82.6	73.4	69.8	70.7	65.5	60.7
0.60	72.0	70.9	86.1	79.9	76.0	76.1	72.3	68.5
0.30	83.4	84.6	90.8	88.6	86.3	85.9	88.3	87.5
0.212	88.3	90.7	94.3	93.6	91.5	91.3	92.6	92.3
0.150	91.2	93.3	95.6	95.8	94.5	94.2	94.7	94.9
0.075	95.2	97.0	97.5	97.9	98.1	97.8	97.6	98.0
<0.075	4.8	3.0	2.5	2.1	1.9	2.2	2.4	2.0

† 4.2% retained on 37.5mm mesh

Propriety

Unless this document is properly acquired by purchase from British Ceramic Research Limited or its appointed agent, it remains the property of the Company and may not be disposed of without its consent. All who acquire it, by purchase or otherwise, must observe the Company's copyright and must not reproduce or copy any part of it without permission.

CERAM Research
Queens Road Penkhull Stoke-on-Trent ST4 7LQ United Kingdom
Tel:01782764444 Fax: 01782 412331 E-mail info@ceram.co.uk
http://www.ceram.co.uk