TRRL Laboratory Report 691

TRANSPORT and ROAD RESEARCH LABORATORY
DEPARTMENT of the ENVIRONMENT

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Bituminous drum-mixing plants in the USA

by

G. D. Goodsall and B. W. Ferne

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BITUMINOUS DRUM-MIXING PLANTS IN THE USA

ABSTRACT

In recent years the United States of America has seen a rapid increase in the use of the drum-mixing process for the production of bituminous materials. The process uses a simplified plant in which mixing takes place in a drum similar to the continuous dryer of a conventional asphalt plant.

This Report describes the findings from a study visit to the United States, in June 1974, by a small group representing the Department of the Environment's Transport and Road Research Laboratory and Engineering Intelligence Division, and a member of the staff of the Amey Roadstone Corporation Limited representing the Asphalt and Coated Macadam Association.

The Report indicates that:

(i) the mixtures produced were well coated and handled in a normal way during paving operations
(ii) the gradings of the mixed materials were uniform but the test results for binder content indicated some variability
(iii) the recovered binder showed less hardening than obtained when mixtures have been conventionally mixed
(iv) the temperatures of the mixed materials were very uniform under the favourable operating conditions
(v) mixing and laying temperatures were similar to those used in the UK
(vi) the effect of the presence of any substantial quantity of residual water on the behaviour of mixtures during paving and rolling, and on the long-term performance of the laid material, has not been established
(vii) there was no evidence to suggest that the service life of the materials produced would be unsatisfactory
(viii) the exhaust emissions could be restricted to very low levels
(ix) the capital and production costs were lower than for conventional plants
(x) the general requirements of the State specifications for coated materials were applied; slightly lower materials temperatures and higher residual water contents were permitted for drum-mixed materials
(xi) a Provisional Specification covering bitumen macadams, with penetration-grade bitumens, and rolled asphalt base and basecourse mixtures could be issued
(xii) further evidence was required of the suitability of the process for the production of wearing course rolled asphalt with bitumen and pitch/bitumen binders, tarmacadams and materials containing cut-back bitumens.

1. INTRODUCTION

In recent years there have been several developments in the methods of processing aggregates and binders to produce bituminous road materials. Plant for two processes, the Wibau SL plant manufactured by Wibau Matthias and Co KG and the drum-mixing plant manufactured by at least five companies in the United States, is being marketed; and the final stages of the development of the Coatmaster plant, jointly by Redland Roadstone Ltd and Underground Mining Machinery Ltd., have been reached. Although each of these processes is different in detail, they all have two common features. Firstly the pre-drying and/or heating of the aggregate as a separate operation from the mixing process has been eliminated. Secondly these operations, including the mixing process, all take place in a rotating drum which is either of a similar design to the continuous dryer fitted to conventional asphalt plants or, in the case of the Coatmaster plant, of a design that is closer to that used on ready-mixed concrete trucks. One further feature of these new processes is their potential ability to be operated with a much-reduced dust emission; this is largely because the aggregates are in a 'wet' condition, either with moisture or binder, throughout the process.

Early in 1974 both the Boeing Construction Equipment Company and the Barber-Greene Company contacted the Department of the Environment and bituminous-materials producers in the UK to sound out their reaction to the possible introduction of the drum-mixer type of plant. Both companies described the principles of production and showed different plant configurations at a wide variety of sites on which the plant was being used. The general impression given was of reduced capital outlay, lower running costs and much-reduced dust emission without elaborate and costly dust-suppression equipment; all of these advantages should be of ultimate benefit to the community.

As with the Wibau and Coatmaster processes the requirement of British Standards 594[1] and 4987[2] for the aggregate to be thoroughly or adequately dry before coating is not fulfilled. For this reason official recognition and acceptance of the new process is an essential prerequisite for its use in the UK.

Apart from the difficulty about the specified requirement for aggregate dryness, acceptance of the drum-mixing process is also influenced by the reluctance of the producers of bituminous materials to use a continuous process. This partially reflects the difficulties in organising production to cover the range of products that the supplier in the UK is normally expected to be able to offer at short notice. Nevertheless the possibility of having an efficient, high-output plant available, economical to operate under UK conditions, is still attractive to producers of bituminous materials.

Subsequent to the initial approaches by the American companies discussions were held between the Asphalt and Coated Macadam Association and the Department of the Environment. As a result it was decided that more first-hand information was required to assess effectively the performance of the drum-mixing process and the quality of the material produced.

This Report describes the observations and findings of a study tour to the United States undertaken by a combined team from the Department and ACMA. The members of the team were:

G D GOODSALL	Transport and Road Research Laboratory	Department of the Environment
B W FERNE	Transport and Road Research Laboratory	Department of the Environment
R LOBER	Engineering Intelligence Division	Department of the Environment
C R CURTIS	Amey Roadstone Corporation Limited representing ACMA.	

The visit lasted from 28 May until 21 June, 1974; R Lober was with the team until 14 June.

2. DEVELOPMENT OF THE DRUM-MIXING PROCESS

It is believed that the earliest use of a drum to produce bituminous mixtures suitable as road materials was at the beginning of this century. Even so, it was not until the early 1950's that the McConnaughay Company in the USA succeeded in promoting a process in which the aggregate was coated with hot emulsion in a rotating drum. In 1959, elsewhere, a further development took place when materials were first produced in a rotary dryer with penetration-grade bitumen as the binder. At that stage, little support was forthcoming for this new approach and little further was achieved until 1969. In that year the McConnaughay organisation patented a process in which bitumen and certain chemicals were added to the aggregate as it was being heated in a conventional contraflow continuous rotary dryer. From the time of this innovation the development and refinement of the process has been more or less continuous so that, in 1970 and 1971, projects in Iowa were paved with material produced in a McConnaughay-designed plant. Also, in 1970, Tim Shearer became actively involved in carrying out comparative trials of mixed materials produced using a relatively crude drum-mixing plant and a conventional plant.

Following this work there was a considerable upsurge in interest. Currently, five plant manufacturers in the USA are marketing plants that use a rotary drum for the mixing process. These are:

Barber-Greene Company, Aurora, Illinois
Boeing Construction Equipment Company, Renton, Washington
Cedarapids, Iowa Manufacturing Company, Cedar Rapids, Iowa
CMI Corporation, Oklahoma City, Oklahoma
Stan-Steel Corporation, Vernon, Los Angeles, California

Each of these companies has produced plants but by far the greatest number in use in mid-'74 had been supplied by the Boeing Company. There appears to be a mounting demand for the plant manufacturers in the USA to be able to supply this competitively-priced equipment and the situation depicted above may change rapidly.

3. OUTLINE OF THE BASIC DRUM-MIXING PROCESS

Although there are differences in design detail between the plants supplied by the various manufacturers there is a common basic process which is shown in diagrammatic form in Figure 1.

The stockpiled aggregates are fed, in their natural state, by mechanical shovel into a multi-bin cold feeder. The different sizes of aggregate are blended by volume from the feeders and any necessary filler added at this point. The combined aggregates are then fed by belt to the drum-mixer over a belt weigher. The precise arrangements for adding the binder tend to vary from plant to plant but, essentially, the aggregate is passed through the drum-mixer and at some point during the drying and heating operations the hot binder is added. The binder is metered by pump and the actual flow rate at any instant is adjusted automatically according to the signal from the belt weigher. Within the drum the aggregate is dried, heated and mixed with the hot binder; these operations are continuous in approximately the order given but not entirely discrete.

On discharge from the drum-mixer the mixed materials are handled in a conventional manner with at least some provision for temporary storage because of the continuous nature of the process.

The whole process is relatively simple and several items of plant that are normally essential on a conventional asphalt plant are not required. These include hot-aggregate elevator, screening deck, hot-aggregate storage bins, weigh hoppers and pugmill.

4. PURPOSE OF VISIT

The main purpose of the visit was to observe plants in operation and to study the drum-mixing process at first hand. From available information about the process and a basic knowledge of the properties of bituminous materials, the following fairly comprehensive list of items that were of prime interest to the party was produced:–

(i) Work related to the uniformity of the product, ie any special investigations of the consistency of the composition.
(ii) Work on changes in the binder properties during mixing over a wide range of grades of binder.
(iii) Investigations of the effect on road performance of residual moisture and of the possible extra risk of stripping especially with aggregates known to be suspect in this respect.
(iv) Road performance of drum-mixer-produced materials under heavy traffic.
(v) Information about any failures of material on the road.
(vi) Locations and details of any projects aimed specifically at critically assessing drum-mixed materials.
(vii) Information about mixtures produced with aggregates of maximum size in the region of 40mm.
(viii) Locations where the potentially more 'difficult' aggregates have been treated eg absorbent gravels and limestones, blastfurnace slags and very wet or very dusty aggregates.
(ix) Difficulties in thoroughly incorporating up to 10 per cent of filler in the mix.
(x) Operational difficulties in running this type of plant eg any additional risk of fire.
(xi) Measurements of the emissions from the exhaust stack and any specific regulations covering emission control.
(xii) Differences in the behaviour of drum-mixer-produced material during paving operations with particular reference to compaction.
(xiii) Any side-by-side comparisons of materials produced by the drum-mixer and the conventional process.
(xiv) Special specification requirements issued to cover materials produced by the new process.
(xv) The economics of the process.
(xvi) Any other items on which research has been carried out or is planned.

It was always envisaged that an essential part of the visit was to spend sufficient time at the production units to understand and examine how the plant and process was likely to affect the material produced. The ACMA representative had the task of ensuring that the general engineering and routine production aspects of running this type of plant from Industry's point of view would be adequately covered.

5. PREPARATIONS FOR THE VISIT

It was clear that there was a rapid growth in the use of the drum-mixing process in the USA and that many of the States and other organisations had carefully considered the implications of allowing its use. Therefore, as a first step in the preparations for the visit, direct approaches were made to:–

(i) the States known to have had experience of the process by early 1974
(ii) the States that bordered those with experience
(iii) the Federal Highway Administration
(iv) the National Asphalt Pavement Association (NAPA)
(v) the Asphalt Institute and
(vi) the University of Idaho.

The response to this request for help was most gratifying and it was soon realised that it would not be possible to accept all of the invitations to discuss the process and the attitudes of the various organisations. It was therefore necessary to select most carefully those places which should be included in the itinerary to ensure the achievement of the objects of the visit. It was also considered that the most likely plant producers to offer drum-mixing plants in the UK in the near future would be the Boeing and Barber-Greene companies; therefore the visit should be limited to observing the plant produced by these companies. The actual places visited and the people met are listed in Appendix 1. Fig.2 shows the States visited and also those contacted.

6. PLANT AND MODE OF OPERATION

The Boeing and the Barber-Greene plants are based on the same principles of operation but have minor differences in design. The plants and processes were still undergoing refinement to improve the overall efficiency of operation and to suit the variety of working conditions under which they may be required to operate. It should also be emphasised that in some parts of the USA it is quite normal to move a plant onto a site for a single job and then to move on to a new site with the least delay possible. To meet these requirements the drum-mixing plant has generally been designed for the utmost ease of transport and setting up.

6.1 Aggregate stockpiling and cold-feed system

The grading of the final product from the drum-mixing process depends very largely upon the efficiency of the handling of the aggregates. The actual method of handling adopted on any one site was chosen taking account of the source and type of aggregate and the method of preparation of the aggregate for use. Unlike operations in the UK where it is usual to draw supplies of the required materials from stocks of single-sized aggregates, in the USA the stockpiles commonly covered a range of sizes.

The general approach to stockpiling was influenced by the attitude of the customer for the mixed material. When a State was the purchasing authority the minimum number of stockpiles was often specified and varied from 1 to 3 depending upon the State and the maximum size of aggregate permitted by the specification. For a site producing mixed material of 20mm maximum size, a typical arrangement was for the aggregate to be stockpiled in three sizes: large coarse aggregate, small coarse aggregate, and sand, though on two sites a single stockpile of 20mm-down aggregate was used.

On the whole very large stockpiles, many in excess of 10,000 tonnes, were evident and, even when there was a range of sizes in one stockpile, there was extremely good management and surprisingly little segregation.

From the stockpiles, which on big jobs were receiving constant attention to maintain their uniformity, the aggregates were transferred by mechanical shovel, in the usual way, to a 3- or 4-bin cold-aggregate proportioning unit (see Plates 1 and 2). In most cases the size of each bin was adequate to prevent undue contamination of material in one bin from the next but, with aggregate grading being completely controlled at the cold feed, it was essential for care to be exercised.

Provided the stockpiles are uniform and the transfer to the aggregate cold-feed bins is carried out efficiently, the consistency of the grading of the final product very largely depends on the accuracy of the proportioning system from the bins. Although the precise configuration varied from site to site the mechanics of the proportioning were always the same. The aggregate was drawn from each bin, through an adjustable gate, by a variable-speed belt (see Plate 3). By the usual method of gate adjustment and variation in belt speeds, the discharge rates of the different sizes from the bins were established. Thereafter, the final grading was determined by simply resetting the belt speeds for each particular specified grading.

On two of the plants facilities were included for the addition of filler. In one case provision was made for the filler to be added to the collecting belt beneath the aggregate cold-feed bins such that the filler was sandwiched between the aggregate on the belt (see Plate 2). In the other case the filler was added at an aggregate transfer point (see Plate 1) where again a certain degree of blending was accomplished. In both cases the filler was volumetrically proportioned using a screw conveyor from a storage silo.

After some of the early work with the drum-mixing process it was strongly recommended that there should be interlock between the aggregate feedrate and the rate of binder addition to ensure accurate proportioning. In current State specifications (see Appendix 2) there is usually a requirement for an aggregate belt-weigher, or similar device, to be fitted; this was fitted on each of the plants seen. On some plants the weigher was mounted on the conveyor belt transferring the aggregate to the mixing unit (see Plates 4 and 5) but on some of the more recently-produced plants the weigher was made an integral part of the collecting belt under the cold-aggregate feed bins (see Plate 6). This latter arrangement made for a more compact plant with advantages when changing the site of production. When the belt weigher was included within the structure of the cold bins, it was necessary to modify the discharge direction of the last bin to provide a sufficient length of fully-loaded belt before the weighing idler.

6.2 Mixing Unit

The mixing unit was essentially similar to a continuous rotary dryer (see Plate 7). The sizes of the units ranged from 5.5m long by 1.2m diameter for a 60-tonnes-per-hour output to 12.2m long by 3.1m diameter for an output of 500 tonnes per hour. The internal fittings have been arranged to provide a sequence of operations that produce a thoroughly-mixed end-product at the required temperature.

Two systems were used for the transfer of the proportioned cold aggregate to the drum. In one the aggregate entered the drum so that it passed beside the burner flame (see Plates 8 and 9) and, in the other, the aggregate was impelled into the drum, below the burner, from a fast-moving belt (see Plates 5 and 10). For the below-burner entry to the drum a shorter conveyor belt from the feed bins could be used; this is an obvious advantage with a portable unit.

Once the aggregate was in the rotating drum the drying and heating part of the process commenced. The source of heat was a conventional burner which was mounted at the aggregate input end giving uniflow conditions. It is believed that the burner position is chosen such that the incandescent part of the flame does not penetrate too far into the drum where the binder may be affected. Burners were designed to operate with all of the usual types of fuel and the choice appeared, to some extent, to depend on the local availability. The noise emitted by the burner was, on occasions, of some concern and it was indicated that a purpose-made muffler was available should it be required.

The position for the addition of the binder has varied from time to time during the development of the process but there now appears to be some standardisation. For all of the plants visited the binder was pumped onto the aggregate inside the mixing drum through an open-ended pipe, the only variable now being the actual distance inside the drum to the outlet point. This distance varied from 10 to 40 per cent of the drum length. The final choice of the precise distance inside the drum was decided by the plant supervisor with the object of controlling the emission of both particulate matter and smoke from the exhaust stack. Such factors as the dustiness of the aggregate, the moisture content of the aggregate and the local opinions on the possible harmful effects of the burner flame on the binder were considered.

The System for controlling the aggregate/binder ratio was designed to respond to the quantity of aggregate passing over the belt weigher, to make an adjustment for the moisture content based on an estimate from past experience or on a test measurement, and then to pump the required quantity of binder into the drum to give an appropriate binder content. Allowance was made for the time lag between sensing the aggregate weight and the addition of the binder.

The general arrangements for the transfer and mixing of the material inside the mixing drum were all similar but varied in detail. The first section of the drum was designed for rapid movement along the drum in the region of the flame. In the next section, as the drum rotated, the material cascaded from the lifting flights forming a curtain for the efficient removal of water, heat transfer and mixing. It is most probable that the curtain of material also acted as a filter and removed some of the particulate matter from the gas stream. Finally there was a very short section designed to ensure smooth discharge of the mixed material from the drum.

The temperature of the end product was controlled by suitable adjustment of the heat output of the burner. Provision was made for automatic control of the burner which depended upon the temperature of the material leaving the mixing drum, measured by a sheathed thermocouple. On several occasions, manual control was being exercised but no clear-cut reason was given for operating in this way. On the whole, records showed very effective temperature control; this probably reflects the ease of operation when feeding aggregates from very large stockpiles with little variation in moisture content.

6.3 Handling and storage of mixed materials

After discharge from the drum the mixed material was transferred by slat conveyor, bucket elevator or rubber-belt conveyor to some kind of storage facility. The transfer method chosen was left to the particular plant operator. The rubber-belt conveyor, although not ideal from cleanliness of operation, was the lightest and most easily transported of the three options. The choice between the slat conveyor, which is frequently used for handling mixtures, and the bucket elevator appeared to be influenced by the possible lower maintenance costs for the bucket elevator: previously the bucket elevator had been considered unsuitable for handling coated materials but doubts about these were now fewer.

The arrangements for storage varied widely because of the different outputs of the plants and the different ways of managing the jobs (see Plates 11, 12 and 13). The simplest storage facility amounted to no more than a holding hopper to permit continuous operation of the plant during lorry changes; on the other hand, a plant that was set up as a permanent installation had 3 storage silos capable of holding a total of 600 tonnes of mixed material.

6.4 Dust-suppression equipment

There was neither a common approach nor a general solution to ensuring that the discharge from a plant would meet the local requirements. At all plants visited there was a sensitivity to the possibility of the local inspector deciding to close down the unit because of unacceptable emissions but, with the lack of consistency in the approach of the various authorities, a wait-and-see attitude was frequently adopted.

At the sites visited only two types of dust-suppression equipment were seen. On three plants a wet scrubber was in use (see Plate 14) and on one a scroll cyclone was fitted. The scroll-cyclone system concentrated the dust at the periphery of the scroll, bled-off this outer layer and returned it to the feed end of the mixing drum (see Plates 15 and 7). On four of the plants no dust-suppression equipment was employed (see Plates 11 and 16). A multiple-cyclone unit was also mentioned as a possible alternative arrangement.

6.5 Visual aids for plant control

Apart from the plant-control equipment already mentioned ie 'infinitely' variable aggregate proportioners, aggregate/binder ratio controller, temperature/burner regulator, there were also several visual aids on the control panel. These included a mixed-material temperature indicator and recorder, a controller and indicator of the burner setting, an exhaust-stack temperature indicator, and indicators for the quantity of binder being added, at any instant, in gallons per minute and the rate of production in tonnes per hour.

7. DRUM-MIXING PLANT INSTALLATIONS, RAW MATERIALS PROCESSED AND THE MATERIALS PRODUCED

In the course of the visit, it was found impossible to predict, with any great certainty, the actual production programme in a particular area. This was a reflection of the widespread use of mobile plant which is set up for an individual contract which may be of relatively short duration. Also the ease of erection, dismantling and transportation of the drum-mixing plant has encouraged the Contractors who specialise in this kind of operation to invest in this type of plant. Thus, it was necessary to accept opportunities of seeing working plant as and when they arose, even though this meant that the proportion of the higher-output plants seen was greater than would have been preferred.

7.1 Description of plant-sites visited.

The following descriptions of the operations at the plant-sites visited have been arranged according to the potential output of the various units. Summarised details of the plants and raw materials processed are given in Tables 1 and 2.

7.1.1 Very-high-output units – 500 tonnes per hour

7.1.1.1 Sparks, near Reno, Nevada. The plant on this site was owned by Robert Helms Construction and was a Boeing Model 600. The plant was set up in March 1974 on a site adjoining the Company's gravel workings. Because of the permanent nature of the operations on this site the arrangements were somewhat unusual with a higher capital investment in the ancillary equipment than was seen elsewhere. A general view of this plant-site is shown in Plate 17.

There was a four-bin cold-aggregate feed-proportioner with a facility for adding filler by screw conveyor to the collecting belt beneath the bins. The belt conveyor to the mixing drum was fitted with a device to measure the belt speed and thus improve the accuracy of the estimate of the aggregate weight passing over the belt weigher. The aggregate entered the mixing drum at a high level via a divided chute which passed the material either side of the burner flame. The burner was normally supplied by natural gas from the town main but this provision was inadequate for maximum production; as an alternative, diesel-oil could be used. The binder was stored in underground tanks and metered to the mixing drum where it was discharged onto the aggregate at about 5m from the burner end of the drum. The mixed material leaving the drum was transferred by slat-conveyor to a three-silo storage unit capable of holding a total of 600 tonnes. There was also a facility for rejecting at the outlet from the drum the small quantity of waste material that occurs on start-up,when changing mixes, or when there is a plant malfunction. The exhaust gases from the mixing drum were passed through a venturi fitted with a wet-scrubber before discharge into the atmosphere through a 6-metre-high stack (see Plate 14). The aggregate was the local gravel with a high content of crushed material. It was stocked in 3 sizes, 25mm–10mm, 10mm down, and sand, in massive stockpiles which appeared uniform. The bitumen being used was grade AR4000* (85–100 penetration). Storage was also provided for MC250, a medium-curing cut-back bitumen which had so far not been mixed but it was expected that a 'cold-mix' material would be produced successfully in due course.

The materials produced by this unit were:

(i) "Fine" fines – sand with 9.5 per cent bitumen
(ii) Fines – 40 per cent 10mm down, 60 per cent sand, with 7.5 per cent bitumen

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* AR4000 is a bitumen with a viscosity of 4000 poises at 60°C; this is approximately equivalent to 85–100 penetration.

(iii) Regular mix – 40 per cent 25mm–10mm, 60 per cent 10mm down, with 5.5 per cent bitumen, and
(iv) Open grade (friction course) – 85 per cent 10mm down, 15 per cent sand, with 6.5 per cent bitumen.

The highest output so far achieved was 480 tonnes per hour with a 7-hour total of 3100 tonnes. Batches as small as 20 tonnes were produced.

Indications were that temperature control using the automatic system supplied was good with a typical working range of about 10°C.

The plant supervisor said that 'the aggregate contained about 6 per cent of moisture and there had not been any trouble with dust emission. When operating at 115°C there was no noticeable difference in smoke emission when using either natural (town) gas or diesel burner fuel; even so, smoke had been emitted at temperatures as low as 125°C'. The reason for the emission of smoke was not known but reference was frequently made, at this and other sites, to the variable quality of the available bitumens and, in particular, to the possibility of the bitumen fuming at the mixing temperature. Overall the Helms Company were well satisfied with the performance of the plant over the limited period of use during which about 60.000 tonnes of material had been produced.

7.1.1.2 Arlington, near Everett, Washington. The Boeing Model-600 plant on this site was being operated by the Associated Sand and Gravel Company and was being used, at various times, by Boeings as a test-bed to examine modifications to the plant. The plant was not in operation during the visit. A general view of the plant is shown on Plate 18.

There was a three-bin cold-aggregate feed-proportioner delivering a pre-blended 20mm-down crushed morainic gravel. The binder being stocked was of 85–100 penetration.

The plant, which was installed in the late summer of 1973, had been run on only 25 days during which some 30,000 tonnes of material had been produced. Of this material 10,000 tonnes had been supplied in October 1973 as part of a joint co-operative investigation by Washington State and the Asphalt Paving Association of Washington. In the long run, this project requires in excess of 100,000 tonnes of material. Up to May 1974 the materials produced have been:

(i) Asphalt-treated base – a dense continuously-graded material with about 4 per cent of binder.
(ii) Asphaltic concrete, 14mm maximum-size crushed (75 per cent) gravel with 5.5 per cent binder.

No particular problems had been experienced with the operation of the plant although some blue smoke was reported as being emitted at temperature around 125°C. Some doubt was expressed about the ability of the plant to meet the State requirements for emission but it was apparent that further plant modifications had been carried out on the emission control. The plant had been supplied with cyclones for dust suppression but more recently a venturi with wet-scrubber had been fitted. It was understood that the new exhaust arrangement was supplied and fitted at the request of Boeings.

7.1.2 High-output units – 350 tonnes per hour

7.1.2.1 Shell Rock, near Waterloo, Iowa. The plant on this site was owned by Everds Brothers Construction and was supplied by the Barber-Greene Company in June 1972. The plant designation was DM70 and it was one of the earliest drum-mixing plants produced by Barber-Greene (see Plate 19). Modifications to the original plant had been carried out by the owners, in co-operation with the plant manufacturer, to increase the output of the burner and to improve the emission characteristics of the plant. It was also indicated that further developments to improve the all-round efficiency were under consideration.

There was a standard 3-bin cold-aggregate feed-proportioner from which the aggregate was passed through a scalping 'screen' onto a belt conveyor to the top of the mixing drum. The conveyor was fitted with a belt weigher which was protected from the wind to improve its accuracy. The 'new' burner was fixed on a temporary mounting well back from the mouth of the drum giving only a short length of flame inside the drum. Diesel fuel was being used. The binder was discharged about 4m from the burner end of the drum. The mixed material leaving the drum was transferred by slat conveyor to a storage hopper which contained, within the structure, a facility for rejecting waste material.

The ducting for the exhaust gases at the outlet end of the drum had been considerably enlarged to reduce the quantity of particulate emission from the stack; also the multiple-cyclone system originally supplied had been replaced by ducting with a venturi and wet-scrubber. The particulate emission from the exhaust stack was very low.

The 'coarse aggregate', 20mm maximum size, was a rather soft and dusty limestone quarried some 6 km from the plant site and the fine aggregate was a washed sand from the adjacent pit. The bitumen was of 85–100 penetration. The material being produced was a dense mixture with 30 per cent of sand and 70 per cent of the limestone which contained some 40 per cent of dust; this gave a total of some 55–60 per cent passing a 3mm sieve. The bitumen content was 6 per cent. The mixing temperature was very uniform at 135–140°C within the normal working range of 120–150°C for this type of mix.

The mixture leaving the drum was very well coated although there was obviously still a small quantity of moisture present at that time. During the visit the plant was being run with a throughput of 190–230 tonnes per hour although a maximum output of 400 tonnes per hour had been achieved. The plant was also used to produce a basecourse material of 32mm maximum size and a leaner road base with 3.5 per cent of bitumen. The only other grade of bitumen that had been mixed was of 120–150 penetration.

On the whole the plant supervisors were well satisfied with the performance of the plant. Specifications for composition were readily met and the variability was similar to that obtained on batch plants. The drum-mixing plant was preferred to other types of continuous plant. Less hardening of the binder was found when using the drum mixer.

7.1.2.2 Safford, Arizona. D C Speers Ltd. were the owners of a Boeing Model-400 plant set up in a gravel pit near Safford (see Plate 20). The basic plant was one of the early models supplied by Boeing in September 1972 and, on delivery, no dust-suppression equipment was fitted. Subsequently, to satisfy the local requirements for emission, a scroll cyclone was fitted to the exhaust from the drum in order that the larger part of the particulate matter in the exhaust gases could be fed back into the feed-end of the mixing drum.

The aggregates were proportioned from a 3-bin system. There was an added facility for the addition of 2 per cent of cement filler at the transfer point between the collecting belt from the bins and the feed belt to the mixing drum. The belt weigher was also mounted under this feed belt. The aggregate entered the drum at high level with the bitumen being added partway along the drum.

The mixed material was simply handled through a surge hopper of about 30-tonnes capacity. The material being produced was an asphaltic concrete with 5.6 per cent of AR4000 (85–100 penetration) bitumen and gravel aggregate. The aggregate was partly crushed and of 20mm maximum size. During the visit, mixed material was being produced at 120°C and production was running smoothly at 320 tonnes per hour. Maximum outputs of 450 tonnes per hour and 3800 tonnes in a 9-hour day were reported. The plant operators and the State Authorities were both obtaining consistent results from their regular tests for composition.

While the stack emission was reasonably clean, the overall impression on this site was that the plant emissions were very heavily masked by the general level of dust created by site traffic and the handling of the naturally very dry aggregate. This was common feature on many of the sites but at Safford, in particular, there is a very low incidence of rain and air temperatures were approaching 40°C during our brief visit. Clearly, under these conditions, it would be quite remarkable if site dust could be controlled economically.

7.1.2.3 Richardton-Mott, North Dakota. The plant on this site was also a Boeing Model 400 owned by the Meyer Construction Company (see Plate 21). This plant was similar to but newer than the one at Safford; the main difference was that the aggregate was injected into the drum from a short fast-moving belt mounted beneath the burner. No dust-suppression equipment was fitted.

The gravel aggregate was stockpiled in two sizes, a fairly clean, largely-crushed, 20mm material and a very dusty mixture of 14mm and smaller. The moisture content of the mixed feed was about 7 per cent. 6.5 per cent of 200–300 penetration bitumen was added inside the mixing drum.

The production on this site was thoroughly organised to achieve high outputs with ample transport available to deliver the material to the laying site. A maximum output of 460 tonnes per hour was reported with an average of 370 tonnes per hour. With production running at 420 tonnes per hour, the temperature control was exceptionally good at 105 ± 5°C. The burner, which was very noisy, was fuelled with liquid gas; it was mentioned that temperature control with this fuel was much more difficult at outputs of 250 tonnes per hour and lower.

The stack emission from this plant, with no dust-suppression equipment and at high output, was quite noticeable. There was some evidence of the fall-out of coarse particles of sand close to the exhaust stack. There was also some blue smoke in the exhaust gases which is not unduly surprising with a mixed-material temperature of 105°C for 200–300 penetration bitumen.

The plant supervisors were obviously well pleased with the performance of the plant and were now expecting to reduce the time for setting up on a new site to about 2 days.

7.1.3 Medium-output units – 200 tonnes per hour

7.1.3.1 Bismarck, North Dakota. The plant on this site was owned by the Northern Improvement Company and was a new Model 100 supplied by the Boeing Company (see Plate 22). The essential features were the same as described for the larger models ie 3-bin cold-aggregate feed-proportioner with incorporated belt-weigher, under-burner feed of aggregate to the drum, with the bitumen being added inside the drum. Heat was provided by a burner fed from the town-gas supply; this supply was not adequate to match the maximum potential output of the plant. No dust-suppression equipment was fitted.

The gravel aggregate was fed from 3 very large stockpiles containing a clean 20mm-size crushed gravel, a small pea gravel (5mm–2mm) and a 14mm-down material with a high sand content; this 14mm-down material was very dusty. The mixed aggregate had a moisture content of about 7 per cent. Five per cent of 85–100 penetration bitumen was added to produce a mixed material for a car park.

During the visit production was running at 130 tonnes per hour with a mixed-material temperature of 115°C.

The plant had produced only some 5000 tonnes of material and was not being operated in a fully-automatic mode. The Northern Improvement Company were clearly intending to instal some of their own equipment to control the plant operations; in particular temperature control and moisture sensing were being considered. Nevertheless the production was well supervised and, even with no dust-suppression equipment, the emissions from the stack were very clean.

The plant operators also reported that both slow-and medium-curing cut-back bitumens had been successfully mixed on a small scale. When the medium-curing cut-back had been used there was some 'smoke' as the temperature of the material rose to 80°C.

7.1.3.2 Cameron, Arizona. The plant near Cameron was also a Boeing Model 100 owned by the Northern Improvement Company; it was the first production model of this size (see Plate 23). At the time of the visit production had stopped at the end of the day and it was not possible to discuss the operation of the plant in any detail.

From a limited inspection of the site it appeared that the units that make up the whole plant were very similar to those being used at Bismarck by the same company. Clearly the plant was on a temporary site and the complete set-up was arranged to ensure the utmost ease of transport of the units from site to site. One special feature, to simplify the erection of this plant, was the use of hydraulically-operated rams to position both the conveyor belt, used for transfer of the mixed material, and the hot-mix storage silo.

The plant was not fitted with any dust-suppression equipment and meeting the local emission requirements was proving difficult. There was evidence of some fall-out of grit around the exhaust stack but the quantity was very small.

The limestone coarse aggregate was quarried, crushed and graded on the site, providing two vast stockpiles of 20mm and 10mm stone. The fine aggregate was a quartzite river-sand that had to be brought in; the sand had less than 6 per cent passing a 75-micron sieve. The material being produced was a typical 20mm-down dense mixture with 6.5 per cent of AR4000 (85–100 penetration) bitumen; the binder-content level was higher than usual because of the absorbent nature of the limestone coarse aggregate. The dryness and general nature of the aggregate was also the cause of the difficulties in meeting the local emission requirements mentioned earlier. Up to the time of the visit, the maximum daily output was some 1700 tonnes.

7.1.4 Low-output unit – 100 tonnes per hour

7.1.4.1 Prescott, Arizona. The Boeing Model-80 plant on this site was owned by the Mettler Company and managed by Krugers (see Plate 24). It was the first plant of this size to be manufactured and had been in use for only two weeks.

The essential features of the plant were the same as for the larger plants. Being a fairly new plant, the aggregate feed to the drum was from below the burner. No dust-suppression equipment was fitted.

All the operations on this site were simple. A mixed 20mm-down gravel was fed to the plant from 2 bins of a 3-bin feeder; the proportioned aggregate passed over a scalping screen to the mixing drum where 4.5 per cent of AR4000 (85-100 penetration) bitumen was added inside the drum. Output was running at 80 tonnes per hour, the maximum achieved so far being 115 t/h, at 115°C. An allowance for 2 per cent of moisture in the aggregate was being made. Under the operating conditions described there was a deposition of grit close to the stack and also some evidence of a blue haze.

So far all of the material produced by the plant had been of acceptable quality and there was a general enthusiasm for the new plant.

8. OBSERVATIONS AT LAYING SITES

The materials produced by five of the plants described in the previous section were observed being laid. On each site the materials, which were all basically of the asphaltic-concrete type, appeared to behave in a perfectly normal way.

8.1 Materials from the Sparks, Nevada, and Bismarck, North Dakota, plants

These materials were laid under fairly similar conditions, the Sparks material in a small hospital forecourt and the Bismarck material on a shopping-area car park. Both materials were laid in a single pass so that the finished thickness was about 100mm. Compaction was by conventional tandem roller.

Throughout the laying processes the materials were handled without any difficulties whatsoever and the appearance of the material was very uniform both during laying and after finishing.

8.2 Material mixed at Shell Rock, Iowa

This material was laid on a County road, carrying light local traffic and the occasional heavy farm vehicle. The paving was carried out in varying lengths of about 100 metres to repair sections of the road suffering from foundation failure. Paving operations were straightforward with compaction being provided by a 14-tonne vibratory roller; no vibration was used on the finishing passes of the roller. Throughout the material appeared uniform.

8.3 Material mixed at Richardton-Mott, N. Dakota

The material from this plant was for a 50mm overlay project on 77 kilometres of State Route 8. The plant was set up fairly centrally along the section to be resurfaced. The condition of the existing road was very variable with some areas showing considerable signs of distress. The construction traffic during the resurfacing was likely to be much more severe than the normal traffic using this State road.

All the operations on this project were thoroughly organised for continuous and maximum usage of the mixing and laying plant.

The material during laying looked essentially uniform (see Plate 25) but there were isolated small clayey aggregations in the finished surface; these aggregations had not been broken down during mixing or laying. This was most probably because of the rather dirty, by UK standards, local aggregate that was being used for this project. Even so, State Highway Officials were well satisfied with the material and accepted that the use of locally available aggregates frequently meant that the quality was not as good as would be desired.

The Contractor was laying the material starting at the plant and, therefore, running over the newly laid material, protecting, to some extent, the weak foundations of the existing road. This has led to some failure of the overlay due to the severe stresses caused by the construction traffic and the consequent movement of the underlying material. It is considered that these local failures are in no way attributable to the method of production of the mixed material.

8.4 Material mixed at Safford, Arizona

This material was laid on a major road-improvement scheme on US Highway 70 centred around Thatcher. The road was 14 metres wide and carried heavy flows of cars and some lorries.

Before applying the 100mm overlay of gravel asphaltic concrete the existing road surface had been revitalised by lifting the old surfacing, heating, and mixing with more binder, and recompacting, thus providing a sound base for the new material.

The laying and compaction were proceeding in a normal way with the initial compaction being provided by a pneumatic-tyred roller and the finishing by a steel-wheeled roller. The material, at all times, appeared to be uniform.

8.5 Material mixed at Cameron, Arizona

Although the paving operations were not observed because of the time of arrival on site, it is of interest to note the type of job on which the drum-mixed material was being used.

The project was a joint Federal/State project on State Highway 64 for 9 kilometres of completely new construction comprising a sealed 100mm wet-mix limestone base and a surfacing of 110mm of 20mm-down asphaltic concrete. The main carriageway was 7.5 metres wide with shoulders of 2.5 metres.

From site discussions it was apparent that the project was proceeding smoothly with no problems that could be ascribed to the behaviour of the material.

9. OBSERVATIONS AT SITES WHERE MATERIAL HAS BEEN TRAFFICKED

All of the sites at which materials from drum-mixing plants had been laid could not be visited in the time available. It was decided, therefore, that selected well-documented projects should be included in this part of the study as well as any sites on the intended route. The following brief reports may not be wholly typical of the wider use of drum-mixer-produced materials but they provide an indication of the likely performance of these materials under traffic. The reports are in order of the length of time in service.

9.1 Port Ludlow, Washington

The material laid on this very lightly trafficked housing-estate site was earliest for which any real attempt was made to monitor the process. At the time of mixing, July 1970, the plant consisted of a relatively crude assembly of separate units that were available at the time rather than a properly-engineered complete plant. The mixing process was carried out in a continuous rotary dryer which was being operated under contraflow conditions ie materials travelling towards the burner, and not uniflow as used with modern drum-mixing plants.

An as-dug morainic gravel was passed over a 'grizzly' to produce a mixture that was essentially finer than 14mm; this was then fed through a single hopper to the drum. Binder was added as the aggregate entered the mixing drum and, within the drum, small quantities of tall oil* and aluminium sulphate were added.

The final product was a relatively low-grade dense surfacing material, all passing 16mm and with 55 per cent passing 5mm, suitable for the local traffic. It was laid 40mm thick on a very variable and generally poor sub-base.

After four years of service the surfacing was in good condition especially considering the relatively poor control exercised over this early job. The surfacing was weathering but a small area of material produced on a conventional batch-mixing plant, with the same raw materials, appeared to be in a similar condition. At the same time, the general variability of the material from the drum-mixer appeared more marked.

9.2 Hartstene Island, Washington

By September 1971, the process had been developed to such an extent that the plant used to produce material for a Harstene Island housing-development road system was essentially functioning on similar principles to those used on the modern plants.

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* A coating aid produced in the processing of wood pulp.

For this job it was possible to exercise more control over the aggregate proportioning but, even so, variations in the morainic gravel used were such that complete uniformity was not achievable. The aggregate-feed rate was measured using belt-weighing scales and the flow of binder was electronically linked with this measured feed rate. The binder, 85–100 pen, was added to the aggregate just as it entered the mixing drum.

The materials in the drum travelled away from the burner which was housed in a static extension of the drum such that there was little risk of much direct contact of the materials with the flame.

Reports of those concerned with this project concluded that the process was capable of producing acceptable materials but further controls were required to obtain a greater degree of uniformity.

The mixed material produced was a low-grade dense surfacing material similar to that used at Port Ludlow. It was laid on a clayey-gravel sub-grade to a thickness of about 80mm. After nearly 3 years of very light residential traffic (although it is understood that earlier heavy construction traffic used the roads) the surfacing was in good condition. There were some signs of weathering of the surface and of variability but the general appearance was very satisfactory.

9.3 Eagle Creek – Estacada, Oregon

In August 1972, the State Authorities were approached by the Contractor for permission to use a drum-mixing plant to produce material for this 9.5 kilometre, 48 000 tonne, project. Before agreeing to this proposal the State Officials visited and sought the advice of the North Dakota Highway Department. It was then decided that the surfacing should be treated as an experimental project to enable the State to appraise the process thoroughly.

The laying site was on the Clackamas Highway, State Route 211/224, where a cement-treated base was surfaced with 50mm of basecourse followed by 50mm of wearing course; both mixes were essentially asphaltic concrete with a partly-crushed morainic-gravel aggregate of 20mm down. The binder for most of the project was a 120–150 penetration bitumen of which 5.5 to 6 per cent was required to meet the mix design.

By October 1972, when this project started, the plant had been further developed from that used at Hartstene but the Contractor had had no previous experience of operating such a plant. The plant had a three-bin cold feeder with a Ramsey belt scale which was directly controlling the binder metered on to the aggregate, just before the mixture entered the 2.75m diameter by 11m long drum. The maximum output of this plant was in excess of 400 tonnes per hour.

Although considerable efforts were made to control the production, the data supplied by the Oregon State Highway Division clearly showed a degree of scatter in the results that raised some doubts about the uniformity of the product.Nevertheless the State was generally well satisfied with the product from the new process and accepted that, at the time of the Eagle Creek/Estacada project, there was a need for more experience with such a plant.

The work was carried out under poor paving conditions and this is believed to have resulted in some variability in the compaction achieved, and some loss of quality in the surface finish. Even so, after 20 months' service during which the surfacing had been subjected to quite severe traffic stresses from logging trucks (see Plate 26), the general condition of the road was acceptable.

There were clear signs of variability, even though the surface of the road had been subjected to traffic with studded tyres which tended to mask any differences and there were several areas where the binder content was too high giving rise to 'fat' patches.

9.4 Priest Point, Tulalip Indian Reservation, Washington

In September 1973, a very lightly trafficked County road on the Tulalip Reservation was resurfaced using material from the Boeing–600 plant at Arlington and, alongside, similar material from the conventional plant stationed at the same site.

Although these materials had been in use for only some 9 months there was quite marked evidence of the effect that studded tyres have on the surfacings. Nevertheless the two materials appeared to be behaving in exactly the same way.

9.5 Arlington, Washington

The Washington State Highway Department and the Asphalt Paving Association of Washington have a joint research project to examine the process and materials produced by the drum-mixing plant. At the time of the visit only a small proportion of the total tonnage, 10 000 tonnes of the 114 000 tonnes provided for, had been produced and the full testing programme had not been started. The material produced was an asphalt-treated base which was a continuously-graded dense mixture with approximately 4 per cent of 85–100 penetration bitumen.

During the early part of October 1973, the asphalt-treated base was laid, 80mm thick, as the bottom layer of the full construction on the new north-bound carriageway of Interstate Highway I 5. At that early stage in the project Washington State were not prepared to use drum-mixed material in the upper layers of the construction without further evidence of the behaviour of the product; this was just a natural precaution and was not due to any doubts about the performance of the material at that time.

The asphalt-treated base had been exposed to the weather over the winter and even in early June site work had not restarted because of the continued poor weather. During this 9-month period the material had been subjected only to the normal site traffic.

Inspection of the laid material showed no signs of anything abnormal and comparison with comparable material on the same site produced by the conventional mixing process was favourable.

9.6 Williams, Arizona

A section of the Interstate Highway I 40 between Williams and Flagstaff had been improved and surface with a medium-textured material produced by the drum-mixing process. The road was a dual carriageway with 2 lanes in each direction carrying a total of about 4000 commercial vehicles per day and was clearly considered an important route by the Arizona State Highway Department.

It was too soon after the completion of the work to make a critical appraisal of the performance of the material but the general impression was of a first-class job with very uniform appearance (see Plate 27).

9.7 Reno, Nevada

An open-textured friction-course material produced on the plant at Sparks was laid on a city street in Reno where the private-car traffic was exceptionally dense. The material had been in service for only about one month, so that no judgement could be made about performance but once again the material appeared to be well-coated and very uniform.

9.8 Camano Island, Washington

During May 1974, an intersection on State Route 532 was resurfaced with an overlay of asphaltic concrete. The material looked well coated and sound but there were considerable differences in the appearance of the finished surfacing at various points on the intersection. It is understood that the temperature of the material was quite sufficient to permit full compaction and the most probable reason for the difference was that the earliest material delivered to the site was of a finer grading.

10. VIEWS OF THE STATE AUTHORITIES

During the initial stages of the preparations for the visit (April 1974) 23 States were contacted to seek information about their experience of and/or views on the drum-mixing process. The States approached were either known to have had some experience or geographically close to areas of drum-mixing activity. Therefore, it should be appreciated that the following summary describing the attitudes of the different States does not necessarily reflect the complete picture over the whole of the USA.

In general it was evident that three different attitudes prevailed:

(i) the plant and process were regarded as simple to control and there did not appear to be any good reason why the material produced should not be uniform. Thus, with adequate specification safeguards to ensure that the material produced was likely to be durable, the overall economics should be attractive.

(ii) it would be prudent to delay a decision about the acceptability of the process and materials until further experience had been obtained, and

(iii) a middle course that limited the risks by restricting the number of projects and/or the position in which the material was laid on the road.

There were, of course, shades of opinion within these attitudes but it is fair to report that in early 1974 the majority of the States contacted were in the third group ie prepared to permit the use of drum-mixing plants under certain conditions.

Where a State was prepared to consider/accept drum-mixed material it was always necessary to amend their Standard Specification. Each State tended to cover the same ground but in slightly different ways. Usually three particular points were dealt with:

(i) the need to ensure compliance with the grading requirements, reference being frequently made to the management of the stockpiles of aggregate;

(ii) a specific requirement for the interlock of the aggregate feed rate with the quantity of binder being added;

(iii) a maximum level for the quantity of residual moisture in the final mix leaving the plant.

There were also limitations on acceptable temperatures of the material both leaving the plant and during laying. At the same time there was a requirement for the density of the fully compacted material which was probably of equal importance.

In a more general way reference was made to the need to prevent any damage to the binder either due to excessive hardening during mixing or because of softening that might occur when the fuel was not being efficiently burnt.

Extracts from the State specifications are given in Appendix 2.

10.1 Particular views of State Authorities visited

10.1.1 North Dakota. The Highway Department in this State was the first to make a real move towards accepting drum-mixer-processed materials. This decision was made at the beginning of 1972 and was based on the potential economic benefits and the expected reduction in air pollution. These benefits were thought to be of such importance that the normal vetting and gradual adoption of a new process was felt to be inappropriate in this case. In 1973 the savings in material costs were estimated to be some $750,000.

Since the introduction of drum-mixing plants into North Dakota the State has built up considerable experience of the performance of these plants and is well satisfied with the product. Materials so far produced are believed to be at least as good as those produced on a conventional plant. The view was expressed that there was a need for some caution when processing very wet aggregates especially when producing mixtures with high binder contents.

The present demand by the State for bituminous mixtures is almost completely met by drum-mixed materials. However, the majority of the most heavily trafficked roads, including the interstate highways, were of concrete construction.

North Dakota and most of the other States visited were doubtful about the continuous attainment of the very low emission levels proposed by the Environmental Protection Agency (see Appendix 4) without the installation of dust-suppression equipment. This concern covered both drum-mixing and conventional plants but the problem was felt to be much less severe for the drum-mixing process as most of the particulate emission was of a 'gritty' nature when the plant was being managed efficiently. North Dakota considered that a simple cyclone would probably be all that was necessary to reduce the particulate emissions to the required level.

10.1.2 Iowa. Discussions with the Iowa Highway Department which, apart from North Dakota, has the greatest experience of the drum-mixing process, gave an impression of a slightly more reserved acceptance of the process but the Department was, nevertheless, prepared to encourage its use, mainly because of the economic advantages. At the time, May 1974, there were no restrictions on the use of drum-mixer materials for the minor roads but on State highways only material for the asphalt-treated base was accepted.

Iowa attached more importance than some of the other States to the need to control aggregate stockpiles and the aggregate feeders and expressed doubts about the uniformity of the binder content of the material produced. On the other hand, with a shortage of good-quality aggregates in Iowa, there was probably a benefit in using the drum-mixing process because of a reduction in the degradation of the rather soft limestones that were the only ones available in some areas.

Iowa also tended to hold strong views on the need to ensure that the temperature of the mixed material was sufficiently high to achieve the required levels of compaction. The minimum temperature specified for all normal work was 110°C, some 15°C higher than specified in some of the other States; however, lower temperatures were permitted, at the request of the contractor, provided the aggregate was well coated, and the density and surface smoothness of the finished material complied with the specification requirements. Also, with materials requiring relatively high binder contents, it was felt that the presence of appreciable quantities of water during compaction could lead to flushing.

10.1.3 Minnesota. Minnesota has also had considerable experience of the use of the drum-mixing process and has followed much the same lines as Iowa. There are no restrictions on drum-mixed materials for roads carrying low traffic flows but its use on more important jobs, where higher-quality surfacing materials are specified, is restricted pending further evidence of good performance under heavier traffic. To assess this performance a 1.5 kilometre length of US route 75 at Warren was surfaced, in July 1973, with an asphaltic concrete containing 10mm-down crushed-rock aggregate and 85–100 penetration bitumen; this is the highest-quality mixture used in Minnesota. So far there had been no serious problems in manufacture or paving and the present restrictions are due to natural caution.

Minnesota differed from other States in its view of the behaviour of drum-mixer materials during laying. It aimed to carry out their laying at temperatures between 105 and 115°C as within this temperature range it was believed that mechanical laying was assisted by the presence of small quantities of water although handwork was more difficult. Between 115 and 130°C there was difficulty in meeting the density requirements for the finished pavement because of the lower water content and the consequent loss of lubrication. Above 130°C it was possible to obtain full compaction.

The State was also originally concerned from its earliest experience lest the riding quality of the finished surface would be poorer than for materials produced by conventional plant; this was not now believed to be a serious matter as with further experience this short-coming had been overcome. However it could be that the sensitivity to temperature/moisture content during compaction might make drum-mixer material more difficult to handle but it should also be added that temperature control under steady production conditions was extremely good.

Minnesota felt that the low emission levels now being asked for by the Environmental Pollution Agency would require the drum-mixing plants to be fitted with a wet-scrubber system especially when production was high for the size of plant.

The State was not convinced that there was much scope for the reduction in tender prices in their State. It was also stated that the prices paid for bituminous materials in Minnesota were a good deal lower than quoted in other States and that margins were probably very small.

For producing hot rolled asphalt wearing course it was felt that the dwell-time in the drum would need to be increased if the 8 per cent or so of added filler were to be thoroughly incorporated in the mix.

10.1.4 Arizona. The Highway Department was as enthusiastic about the economic and environmental advantages of the process as any of the State officials met. Based on its experience and the views of the other States that had examined the process, Arizona had decided to permit drum-mixer material on all classes of highway. This decision was taken in the full realisation that the long-term behaviour of the materials had not been determined but, so far, they had not been able to identify any significant differences from materials produced on conventional plants.

Arizona's approach to specifying all bituminous materials was to concentrate on the properties of the end-product thereby placing the onus on the Contractor to exercise any necessary control over the raw materials and process. This attitude was further strengthened by the application of a system of payment that was related to the composition of samples of the material produced.

As was common in most of the States visited there was no solid evidence of the widespread use of the low mixing and laying temperatures reported for much of the very early work. In Arizona mixing temperatures of 115 to 130°C were normal thus ensuring a minimum of 95°C during laying.

Two aspects on which Arizona had no doubt whatsoever were the real savings in the material costs and the reduction in the emission levels. On the economies there were clear indications that Contractors with drum-mixing plants were submitting the lowest tenders whilst the reduction in the emissions was so obvious that little attempt had yet been made to check the actual levels. The opinion was also put forward that by far the greatest part of the solids in the exhaust gases was deposited within the plant area and therefore the actual quantity of particulate matter was of little environmental importance.

10.1.5 Nevada. The Department of Highways was prepared to accept drum-mixed materials but there were several points of detail upon which it reserved final judgement. It believed that there was still a need for continued careful appraisal of the process and the material produced.

Apart from the general observations made at the beginning of this section, the Department of Highways raised the following specific points:

(i) Where the addition of cement or hydrated-lime was required for mixes produced on a conventional plant, this requirement would also apply to drum-mixer materials.
(ii) There was some evidence of contamination of the final mix when the heavier burner fuels were used. (A similar view has been expressed by other State authorities.)
(iii) Nevada would not recommend the use of medium-curing cut-back grades of bitumen as production at the lower temperatures required for these binders had resulted in some 'lumpiness' of the product; there was also a high risk of the emission of dark smoke and possibly of fire. However, slow-curing grades had been successfully mixed for use in the lowest construction layer.
(iv) It was considered that the requirements of the Air Pollution Board would mean that the exhaust gases should be passed through a wet-scrubber.
(v) Some concern was expressed about the very early behaviour, under traffic, of materials containing appreciable quantities of water. This had led to the permitted residual water being lowered from 3 per cent to 1.5 per cent. By this means the risk of flushing-up and rutting would be reduced but it was suggested that a further reduction to 1 per cent might be necessary.
(vi) Tender prices for one contract showed appreciable savings over material from conventional batch plants but were comparable with prices for continuous plants with cold-feed aggregate control.

10.1.6 Oregon. The Highway Division was obviously interested in the development of the drum-mixing process and had completed two fairly extensive projects to assess its suitability for producing materials of the quality required by the State.

The 48 000-tonne Eagle Creek-to-Estacada project, which was described in some detail earlier in this report (Section 9.3), enabled Oregon to carry out a preliminary assessment of the process and mixtures produced. After this project reservations were made regarding the control of the composition and of the emission levels from the plant but these were considered to be due to the lack of experience with the drum-mixer type of plant. On the second experimental project 50 000 tonnes of 14mm-down asphaltic concrete were produced on the same plant but with modifications aimed at improving the stack emissions to acceptable levels. The emission of smoke could be maintained at the desired level only by operating the plant at relatively low temperatures and by keeping production below the maximum possible output. The asphaltic concrete was laid on the Narrow-to-Valley Falls section of the Fremont Highway north of Lakeview in Southern Oregon.

As a result of its experience on these two projects, Oregon is prepared to permit the use of drum-mixer material on several selected contracts but not to give blanket approval covering all main highway work at this early stage.

The Highway Division still feels that a wet-scrubber with a high pressure drop across the venturi will be required to meet the State's pollution limits; it was also mindful of the need to evaluate whether residual moisture is likely to lead to premature failure of the material. On the other hand, the evidence so far suggests that the binder suffers less hardening during production and this may lead to an increased service life.

For the Eagle Creek-to-Estacada and Lakeview projects there was little apparent financial saving to the State but it is believed that the reduction in capital outlay and the lower running costs, plus a more competitive situation when more plants are acquired by the local contractors, will almost certainly lead to economic benefits for the customer.

10.1.7 Washington. At the time of the visit the Washington State Department of Highways had had little first-hand experience of the drum-mixer process. The Department was most concerned that any decisions regarding the use of the drum-mixer materials on State contracts should be adequately supported by the assimilation of sufficient data to justify the acceptance of the 'new' process. To this end a research project, jointly financed by the State and the Asphalt Paving Association of Washington, was set up to investigate many aspects of the behaviour of the plant and the material produced. It was expected that more than 110 000 tonnes of material would be produced for the project, on the 500-tonne-per-hour plant at Arlington, during which the programme outlined in Table 3 would be carried out. Clearly the research project is aimed at answering many of the questions that are of interest to all potential users of material from the drum-mixing process.

During the initial familiarisation exercises at the Arlington plant the staff of the Department of Highways formed the following tentative views:

(i) the asphalt-treated base produced looked excellent and compacted readily.
(ii) when mixing at 135°C there was little smoke.
(iii) the test equipment being used by the staff of the Federal Highways Administration to monitor the solid matter in the exhaust gases became clogged with coarse particles. It was believed that the fitting of a venturi wet-scrubber to the exhaust system would eliminate any problems with the emission from this plant.
(iv) samples tested showed that the mix was normal and that there were no adverse results.

On a more general level, the Department of Highways had a keen interest in the condition of the binder after processing. In its experience, failure of the surfacing was frequently attributable to excessive hardening of the binder during mixing and exposure on the road. Thus, if the reports of less hardening during processing were a true indication of the general state of the binder in drum-mixed materials then this would most likely lead to an increase in the service life of the road. Even so, there was still some concern about the occasional references to softening of the binder due to contamination with burner fuel.

11. VIEWS OF THE FEDERAL HIGHWAY ADMINISTRATION

From early 1970 various members of the staff of the Federal Highway Administration have observed and carried out detailed studies of the drum-mixing process and of the materials produced.

In January 1970, W L Allen reported on the McConnaughay Process; at that time the binder, additive and water plus a chemical were all being added to the aggregate inside the drum and great emphasis was placed on the 'foaming' that takes place and which is said to assist coating.

Subsequently, attention was paid by the FHWA to the changes in the plant and the process being carried out by the Shearer Construction Company. Also during this period (1971) the Administration followed very closely the early projects in the State of Washington.

The reports of the FHWA on this early work were very enthusiastic about the environmental and cost advantages of the 'new' process. The Administration also gave considerable encouragement to further the use of the process by actively taking part in the initial investigations.

In 1972 the Administration widened its evaluation of the process by carrying out site investigations in collaboration with North Dakota, Iowa and Minnesota, on full-scale projects. Some tens of thousands of tonnes of material, all dense and finer than 20mm, were produced during these studies; the raw materials used covered a range of aggregates with varying properties and grades of bitumen from 80 to 250 penetration.

The findings from the 1971 and 1972 investigations are summarised below:

(i) **Uniformity of mix** – comparable with conventional plant for grading provided effective stockpile management was exercised; acceptable variability of binder content provided there was automatic interlock between the aggregate feed and binder pump.

(ii) **Hardening of binder** – probably less hardening than with conventional-plant mixing and consistently less than found when testing the same binder by the thin-film oven test.

N.B. The weight of evidence supports this statement but the scatter of the individual results raises some doubt about the repeatability of the test and/or the mixing process.

(iii) **Stability of mix** – Hveem tests for stability and cohesion, and immersion-compression tests, on materials produced for the early work in Washington, showed no cause for concern regarding the stability of these materials and no apparent increase in the risk of stripping.

(iv) **Emission levels** – observations supported the view that there was a considerable reduction in the emissions from drum-mixing plants.

(v) **Compaction** – the behaviour of the mixed material during compaction was affected by the presence of moisture; if low placing temperatures were used it was necessary to have some moisture in the mix to achieve the required levels of compaction.

(vi) **Durability of pavement** – the long-term performance of drum-mixer materials was still to be established.

(vii) **Economics** – all indications were that there was likely to be a reduction in the cost of material from 30 to 65 cents per tonne.

Since 1972 the FHWA has continued to monitor the progress made in the acceptance of the 'new' process and still holds to the opinion that a quality material can be produced. Even so, it was apparent that a full understanding of the properties of drum-mixed materials during placing had not been reached.

12. VIEWS OF THE NATIONAL ASPHALT PAVEMENT ASSOCIATION

The National Asphalt Pavement Association has been following the developments in drum-mixing since 1970 through Charles R Foster, its Director of Engineering and Research. In the period from October 1970 to December 1974 NAPA Newsletters have reported regularly on the progress made and, on each occasion, there has been a steadily increasing confidence in the plant and product.

At first the reports were cautious in their acceptance of the new process with the Quality Improvement Committee of the Association recommending:

(i) separate cold-feed controls for each size of aggregate
(ii) interlock of cold feed and binder addition
(iii) moisture-sensing in aggregate to ensure addition of the required amount of binder
(iv) provision of sampling points throughout process
(v) provision of temperature-sensing and automatic burner control
(vi) feed-back of particles retained by a simple dry collector.

By September 1972, it was clear that several of the State authorities were prepared to accept drum-mixed material and NAPA's main concern was to prevent the use of unsuitable make-shift assemblies. To this end the Association advised its members to encourage the specifiers to require the plant to include the items listed by the Quality Improvement Committee. It was also suggested that the quality requirements for drum-mixed material should be exactly the same as for conventionally produced material. There were just two provisos. One was with regard to moisture content; here the proposal was to seek permission, where necessary, for the allowable moisture content in the mixed material to be realistic for materials produced by the drum-mixing process. The second was for the specification of the required level of compaction in the finished material rather than for a lower limit for the temperature of mixing. This second proposal is believed to be the result of the recognition of the fact that little was really known about the factors controlling the compactability of the material produced.

One other aspect of the introduction of drum-mixing plants that was worrying the contractors was the possible difficulty caused through early obsolescence of existing plant. However, the Association's Board of Directors believed that there was no alternative but to face up to the obvious impact that the potentially less costly process was bound to have on the industry. Nevertheless, it was felt that some of the concern was unnecessary as the drum-mixing plants would always be less suitable where rapid changes in the mix type were required.

Throughout these early stages in the commercial exploitation of the process, the Association was positive about two particular points:

(i) there were some savings that should be reflected in a lower cost to the customer; the size of these savings was thought to vary over a wide range but was of the order of 15–75 cents per tonne.
(ii) the control of the emissions was simpler but the very low figures required by the Environmental Pollution Agency would require a wet-scrubber with a high pressure drop across the venturi.

A further assessment of the drum-mixers was issued late in 1974 and the views given then are summarised:

(i) **Acceptability of product** – high with very few 'rejects'. One instance of flushing-up of the surface because of too much moisture/binder in final mix; the binder content was reduced and the fault was eliminated.
(ii) **Plant operations** – easier than for conventional plant. The addition of more sophisticated controls would permit rapid and accurate changes in mix proportions.
(iii) **Emissions** – the total potential emission from the drum-mixing process at the drum discharge was probably about one fifth of that from a conventional process. The particles tended to be gap-graded; particles greater than 150 microns were simple to collect but those smaller than 25 microns would require a wet system. The issue of smoke from the stack was primarily a function of the position of the binder addition and this required optimisation with the local materials.
(iv) **Production costs** – latest estimates (there are no authoritative figures) are for a saving of about 50 cents per tonne.

As a result of this reassessment the Board of Directors of NAPA resolved that:

'Drum-mixing was an acceptable method of producing scientifically proportioned asphaltic concrete.'

13. DISCUSSIONS WITH THE BOEING CONSTRUCTION EQUIPMENT COMPANY AND THE BARBER-CREENE COMPANY

As mentioned in Section 2 of this report, there are at least five known manufacturers of drum-mixing plants in the USA. It was also indicated in Section 6 that both the Boeing Construction Equipment Company and the Barber-Greene Company, the only manufacturers seen during the visit, were engaged in further refinement of the plant to achieve maximum reliability and efficiency. Long and free-ranging discussions took place with the two companies on the engineering and technical aspects of production and development. A few brief comments of a general nature on these discussions are made below.

Both organisations were well aware of the need to understand more fully the sequence of events that make up the whole of the drum-mixing process. In particular, the Barber-Greene Company had commissioned some fundamental work to be done by the long-established Chicago Testing Laboratory. The Boeing Company had the highly sophisticated technology of the parent company available. By mid-1974, it was apparent that there was sufficient confidence in the basic process to commit considerable effort and investment in the manufacture of drum-mixing plants.

There was much common ground between the broad approaches of the two companies. It seemed that their over-riding concern was with the most practical and economic solution to the provision of a plant that would have emission levels low enough to meet the proposals of the Environmental Pollution Agency. This problem was particularly troublesome because emissions from a plant were very dependent on the actual raw materials being processed. Thus, for a particular site, one of several options may be the best solution; these options would include:

(i) scroll cyclones
(ii) multiple cyclones
(iii) wet-scrubbers.

In general, it was considered that only a wet-scrubber with a high pressure drop across the venturi would be efficient enough to meet the EPA requirements. It was also believed that plants would continue to be purchased without elaborate dust-suppression equipment until the regulations were seen to be imposed rigidly.

13.1 Visit to the Chicago Testing Laboratory

Through the Barber-Greene Company, arrangements were made to discuss the investigation carried out by the Chicago Testing Laboratory of Northbrook, Illinois, into the manufacture of materials by a simulated drum-mixing process.

During the visit the Testing Laboratory demonstrated the use of a small-scale batch process to simulate the continuous drum-mixing process. Essentially the cold, damp aggregate and hot binder were transferred to a drum 400mm in diameter by 330mm long. The drum was closed and rotated; heat was supplied directly to the materials in the drum by a gas-fired burner. Throughout the test, the temperature, moisture content and flue characteristics were recorded and visual observations made. The final product was examined for stability, cohesion and penetration of recovered binder.

Several different types of material, including open-textured base material of 50mm down, had been processed during the investigations and a brief summary of some of the findings is given below:

(i) coating with bitumen of 80–100 penetration was assisted by the moisture on the aggregate vapourising and causing the binder to foam at temperatures of about 95–105°C
(ii) the greater part of the moisture remaining in the materials after mixing at temperatures of 90–100°C readily evaporated
(iii) the densities of materials compacted under standard compactive effort at 90–100°C were lower than for materials compacted at higher temperatures; under the same compaction conditions stabilities were also lower
(iv) hardening of the binder was less than for conventionally-produced laboratory mixes
(v) there was no loss of strength after immersion in water at 60°C for 24 hours.

Thus the findings from this laboratory investigation confirm the pattern of behaviour reported by many observers of the full-scale process.

14. REVIEW

In the previous sections of this report the plant and its mode of operation, the plant sites and laying sites, and the opinions of the various organisations, have been described in some detail to give substance to the views expressed. This section gives an overall impression from the visit and from the written reports received prior to, during and since the visit. A Bibliography of selected articles from which information has been drawn is given in Appendix 3.

14.1 Plant Operations

14.1.1 Plant sites. Of the 8 plants visited only that at Sparks, Nevada was at a permanent location with the plant erected on properly-cast foundations. At four of the sites the plants had been set up at an aggregate source for a particular job of short duration and the remaining 3 plants were sited at regular sources of aggregate but the plant units were assembled in such a way that transfer to a new site was simple.

Probably because of the temporary use of most of the sites, little effort appeared to be taken in maintaining the general tidiness. For example, where belt conveyors were used to transfer the mixed material to the storage silos there was often a build-up of material that had dropped from the underside of the belt. Another aspect that gave cause for concern, particularly with regard to safety, was the lack of protection for the electrical cables that were supplying the power and carrying the signals for controlling the plant. It was also apparent that the main aim of the plant owners was for the most economic production and that little attention was paid to fine detail, such as accurately adjusting the angle of inclination of the mixing drum: even so there was no obvious detrimental effect on the quality of the material produced.

In contrast, the permanent plant site at Sparks was spaciously laid out and maintained in a very clean condition. Additional items of plant were fitted including a fourth bin on the cold-feed system, a more a accurate belt-weighing system and a by-pass chute with a belt for disposing of reject material.

14.1.2 Mobility and erection of plant. Clearly the plant manufacturers had given considerable thought, when designing the plants, to the provision of readily mobile units. Also, the absolute minimum of site preparation was needed as most of the units were free standing and plant erection, in the normal sense, was not required. This ease of mobility and erection has made the drum-mixing plant particularly suitable for moving onto a temporary site where there is a source of aggregate and where there are no permanent mixing plants within a reasonable distance. These conditions probably occur in the areas where the greatest interest has been shown in fostering the use of the new process.

14.1.3 Plant supervision and staffing. There was a large measure of agreement among the plant managers that the supervision of production was simpler than for a conventional plant and also that the number of staff required to service the processing operations was lower. For example, the staff at the 350 tonne-per-hour Shell Rock plant consisted of a supervisor, a plant operator, a driver for the aggregate-loading shovel, a plant mechanic and a general labourer.

14.1.4 Production of a range of specified materials. It has always been held that continuous processes are much less suitable when frequent changes in composition are required. In the UK, with the multiplicity of mixtures covered by the specifications, one of the basic requirements has been that the mixing plant should be capable of a high degree of flexibility. In the USA there is a lower demand for this mixed-production capability. More recently where there has been a range of sizes of aggregate available and multiple hot-storage facility, it has been possible to organise production to encompass a variety of mixes. Clearly a great deal will depend upon the management of such a system, but it would appear that the unsuitability of the continuous process for the production of small quantities of material of different types may not be a serious disadvantage.

14.1.5 Mixed-material temperature control. There was ample evidence that temperature control was very good during periods of continuous production. The use of large stockpiles of aggregate with consistent moisture contents and the normal production of only one type of material made temperature control simple. This was reflected in very small variations in the temperature of the mixed materials leaving the drum. Further, when production was of a single type of material, it was found advantageous to stop the plant for brief periods, without emptying the drum, to match output to demand. By this means the fluctuations in mixed-material temperature that occur during start-up and run-down were minimised.

14.1.6 Emission control. Although the loading of the gases being exhausted from a drum-mixing plant is generally much lighter than the loading before treatment from a conventional plant, it is still probable that some form of dust-extractor will be necessary to comply with the latest UK regulations. Currently plant manufacturers have no fixed policy regarding the equipment required because of the wide variety of local conditions of use, but it is recognised that the firm application of the proposals, outlined in Appendix 4, will demand some attention in the UK and the USA.

In practice there were two separate aspects of emission control of concern to the plant operators in the USA. The most urgent consideration in mid-74 was to comply with the opacity levels required by the local inspectors and thereby to prevent any risk of shut-down of the plant. In the longer term, the proposed application of the new low limits for particulate emissions would impose the need for much more stringent control over dust suppression.

To meet the opacity requirements it will be necessary for the plant operators to control the emission of dust and to make allowance for the temperature/'smoke' characteristics of the binder being used. The position of addition of the binder was also believed to affect the level of smoke emission.

The control of particulate emissions is much more complex because of the interaction of several factors. Alternative systems were available ranging from a very simple scroll cyclone, through multiple small cyclones to wet-scrubbers with a high-, medium- or low-pressure drop across the venturi. Bag-houses fitted with fabric filters have not been considered suitable because the gas-borne particles tend to be contaminated with binder and would adhere to and clog the fabric.

It was commonly believed that rigorous application of the Environmental Protection Agency's proposals would demand the use of a wet-scrubber. Nevertheless, with aggregates containing appreciable quantities of moisture, a judicious choice of position for the addition of the binder and a throughput well within the maximum rating of the plant would obviate the need for elaborate dust-suppression equipment.

14.1.7 Fire risk. From the earliest use of the drum-mixing process, where the burner flame is within the mixing chamber, there has been considerable apprehension about the possible increase in the fire risk. With the initial use of contra-flow conditions in the drum there was an obvious additional risk because of the fluid state of the binder in close proximity to the flame zone. Currently the risk has been greatly reduced by the use of the uniflow conditions of operation.

There have been instances of fire in the drum but, as far as is known, no situations in which fire has not been easily controlled. Early fears are felt to be largely unfounded.

14.1.8 Economics of production. It has not been possible to obtain accurate, valid and comparable data on the relative economics of the alternative processes.

Charles Foster of NAPA would not expect to receive such information from his members and, for the benefit of his Association, theoretical assessments of the probable savings were commissioned. From these studies estimates of savings were of the order of 65 cents per tonne.

The most significant indication of the expected benefits to the producers is the rate at which drum-mixing plants are being purchased. Obviously the decisions to invest capital are based on commercial assessments of the operation of this type of plant. As the financial advantages to the producer should lead to an improvement in his competitive position, it is not unreasonable to assume that the customer will also benefit from relatively lower tender prices.

14.2 Raw materials processed

14.2.1 Aggregates. On the whole the aggregates were locally-won gravels of mixed origin; crushed limestone was also processed in appreciable quantities. When specifically required up to 3 per cent of Portland cement or somewhat smaller quantities of hydrated lime were added.

14.2.2 Binders. Penetration-grade petroleum bitumens, from 85–100 to 200–300 penetration, were used for practically all of the mixtures. Very limited quantities of base material had been mixed with slow-curing cut-back bitumen.

14.3 Types of mixture produced

In general only dense mixtures were produced; some of these contained aggregate of 25mm maximum size but, more frequently, the maximum size was 20mm. In one case, no coarse aggregate was included. Binder contents ranged from about 4 per cent for base mixtures up to 9.5 per cent for a sand-mix material. The only other type of commercially-produced mixture that was seen during the visit was an open-textured "friction-course" material. It was understood that some pressure was being applied to encourage the use of materials containing larger sizes of aggregate with lower bitumen demand. So far as could be ascertained the sole attempt to use 50mm aggregate was undertaken in the laboratory-simulation exercise carried out at the Chicago Testing Laboratory.

14.4 Mixing temperatures

The temperatures of the mixtures produced during the visit were rarely below 105°C and were similar to those usually employed in the UK for the equivalent grades of bitumen. At these temperatures and at outputs well within the capability of the plants it was unlikely that there was more than one per cent of 'free' water in the mixture leaving the drum.

14.5 Uniformity

14.5.1 Composition

14.5.1.1 Visual examination. Essentially the materials currently being produced appeared to be uniform at all stages of processing but some of the earliest work was variable. Even relatively 'dirty' aggregates were well coated except for one instance when the aggregate contained clayey lumps some of which persisted in the laid material.

14.5.1.2 Test data. It was not possible to collect sufficient test data to assess the uniformity of composition in a thoroughly sound way. There were indications that the binder content was liable to fluctuate fairly widely but this variability was not of such severity as to cause undue concern to the purchasing authorities. However, if full compliance with British specifications is to be consistently obtained, some attention will have to be given to improving the reliability of this aspect of the proportioning. In all cases the gradings were very uniform even when the analysis showed the test results to be slightly off target.

14.5.1.3 Compliance with State specifications. Clearly the quality offered reflected the system of payment for the material; in some cases, payment was based on a scale of reductions to be applied to the tender prices depending upon the actual deviation of the test results for composition from the agreed target values. Although there were minor deviations which led to small reductions in the payment made there was no substantial evidence of the supply of poor quality material.

14.5.2 Riding quality. From all that was seen the riding quality of the finished surfacing was good; however one State did report that they had experienced some difficulty in obtaining the desired riding quality on their early work. On more recent work they were well satisfied.

14.6 Compaction – effect of temperature and residual moisture.

In many of the early reports on the development of the drum-mixer process it was claimed that full compaction was possible at significantly lower placing temperatures. In general it was believed that this benefit was obtained because of the lubricating effect of residual moisture in the mixed material.

There is most probably a critical balance between residual moisture content and mixed-material temperature on the one hand and compactability on the other. If this is so, any delay in finishing the road surfacing could disturb this fine balance and lead to inadequate compaction. A further indication of the different behaviour of drum-mixed materials was implied by the reference to the apparent loss of workability when handwork was necessary at the lower mixed-material temperatures. It appears, therefore, that any extra mobility is achieved only when the compactive effort is great enough to make use of the lubricating effect of the residual moisture.

No evidence was seen during the visit of the relatively low laying temperatures reported in the early papers and it was clear that there was no full understanding of the properties of the material during compaction. No concerted effort was therefore being made to reap the fuel economies inherent in the use of lower placing temperatures. The hazards in adopting such a course may have been too great to be acceptable.

14.7 Laboratory tests on drum-mixed materials

14.7.1 Changes in the bitumen during processing. A great deal of laboratory work has been done to assess whether any serious changes in the properties of the binder occur during processing. So far there has been no evidence of undue hardening of the penetration-grade bitumens used. In all cases where the bitumen has been recovered for examination, the hardening has been much less than found when using the thin-film oven test on the same bitumen and also less than obtained after processing by conventional mixing methods.

It is of interest to note that there have been several references to the recovered bitumen being softer than the original binder; this was usually attributed to contamination by inefficiently burnt heavy fuel oils.

14.7.2 Residual moisture and stripping. Many of the early reports dealt at some length with the levels of residual moisture in the material leaving the mixing drum and on the road. At that time the mixing temperatures were generally lower than are currently being used and moisture contents up to 3 per cent were recorded. Fears were expressed about the possibility of an increased incidence of stripping of the binder from the aggregate and consequent early failure of the material under traffic. Laboratory tests on samples of drum-mixed material have shown that the loss in strength of mixtures subjected to the immersion-compression test was negligible. It was, therefore, firmly asserted by the various authors that there should be no extra risk of stripping with drum-mixed materials.

14.8 State specifications

The standard State specifications generally described the essential features and performance of some of the items of plant used to produce bituminous materials. Some of the standard requirements precluded indirectly the use of the drum-mixing process and many States issued supplementary specifications which deleted the requirements that did not apply to drum mixers but, at the same time, added extra items such as aggregate/binder interlocking mechanisms on the plant. In a similar way adjustments were frequently made to the specified minimum mixing and laying temperatures, and to the maximum permitted level of residual moisture in the mix. Reference was also made to the need for the producer to prevent any damage to the binder. The standard requirements for compaction and surface smoothness were retained.

15. CONCLUSIONS

The following conclusions are based on the findings from the visit and on the written reports received:

(a) Mixed materials, containing a range of aggregates and penetration-grade petroleum bitumens and produced by the drum-mixing process at temperatures similar to those used in the UK, were well coated and handled in a normal way during paving operations.

(b) The use of consistent stockpiles and accurate cold feeders to proportion the aggregates, together with the aggregate/binder interlock system on the plant, produced mixed materials that generally complied with the specification requirements for composition. Compliance with British specifications for binder content would not be maintained without more effective control of the plant operations but compliance with the requirements for aggregate grading should not be difficult to achieve.

(c) Tests on the binder recovered from drum-mixed materials showed less hardening than is found with binder from conventionally produced mixes. There was a slight possibility of some contamination and softening of the binder when heavy burner fuels were not efficiently burnt.

(d) The use of large stockpiles of aggregate with consistent moisture contents and the normal production of only one type of material made temperature control simple. This was reflected in very small variations in the temperature of the mixed materials leaving the drum.

(e) The mixing temperatures being used during the visit were rarely below 105°C and were similar to those usually employed in the UK for the equivalent grades of bitumen.

(f) At the mixing temperatures used and at outputs well within the capability of the plants it was unlikely that there was more than one per cent of 'free' water in the mixture leaving the drum. No evidence was seen during the visit of the use of the relatively low mixing and laying temperatures reported in the early papers where mechanical compaction was said to be aided by the lubricating effect of 2–3 per cent of residual water. The effect of the presence of any substantial quantity of residual water on the behaviour of the mixed material during paving and rolling, and on the subsequent long-term performance of the laid material, has not been clearly established.

(g) There was no evidence to suggest that the service life of drum-mixed material would be inferior to that of conventionally produced mixtures.

(h) Drum-mixing plants can be operated with very low emission levels provided full account is taken of the following factors:

   (i) the moisture content and dustiness of the aggregate
   (ii) the output of the plant in relation to its rated capacity
   (iii) the dust-suppression equipment required under the operating conditions
   (iv) the position along the drum that the binder is added
   (v) the temperature of the material leaving the drum in relation to the characteristics of the binder being used.

(i) There was a general impression that the economics of the drum-mixing process were attractive to the plant operators and that the purchasers of mixed materials were likely to benefit from lower costs. The capital, running and maintenance costs should be lower than for conventional plant. Also, the basic simplicity, mobility and ease of erection of the plant should lower overall costs especially where plant has to be moved frequently and where high output is an advantage.

(j) Essentially the State specifications demanded the same quality of material from the drum-mixing plant as from conventional mixing plant. Small reductions were sometimes made in the minimum temperatures for production and laying but the usual compaction requirements were maintained. The maximum residual moisture content was generally increased to 3 per cent although in some cases lower figures of 1.0 or 1.5 per cent were specified.

(k) There is no reason why a UK Provisional Specification should not be issued covering all bitumen macadams prepared with penetration-grade petroleum bitumens, and rolled asphalt base and basecourse. Trials would be necessary to establish the suitability of the process for the production of:

(i) wearing-course rolled asphalt, with either bitumen or pitch/bitumen
(ii) tarmacadams
(iii) materials containing cut-back bitumens.

16. ACKNOWLEDGEMENTS

The work described in this report forms part of the research programme of the Construction and Maintenance Division (Division Head: P D Thompson) of the Highways Department of the TRRL.

It is not possible to acknowledge adequately all the help given to the party prior to and during the visit. The success of the visit depended very heavily on Wes Beaty of the Barber-Greene Company, and Bill Harris and Merle Korth of the Boeing Construction Equipment Company. Each person mentioned in the diary, Appendix 1, contributed in some way to the views expressed in the report and the gratitude of the whole party is due to each and every one of them.

17. REFERENCES

1. BRITISH STANDARDS INSTITUTION. Rolled asphalt (hot process) for roads and other paved areas. British Standard BS 594:1973. London, 1973 (British Standards Institution).

2. BRITISH STANDARDS INSTITUTION. Coated macadam for roads and other paved areas. British Standard BS 4987:1973. London, 1973 (British Standards Institution).

TABLE 1

Summary of details of plants

Location	Sparks Nevada	Arlington Washington	Shell Rock Iowa	Safford Arizona	Richardton /Mott N. Dakota	Bismarck N. Dakota	Cameron Arizona	Prescott Arizona
Make	Boeing	Boeing	Barber-Greene	Boeing	Boeing	Boeing	Boeing	Boeing
Model	600	600	DM70	400	400	100	100	80
Efficient output range* tonne/hour	300–650	300–650	–	250–450	250–450	100–250	100–250	70–150
Burner fuel	Gas	Oil	Oil	Oil	Gas	Gas	Oil	Oil
Drum dimensions m.	12.2 x 3.1	12.2 x 3.1	9.1 x 2.7	11.0 x 2.6	11.0 x 2.6	9.1 x 2.1	9.1 x 2.1	6.7 x 1.5
Length of drum before binder added m.	5	5	4	2	1	1	–	1.5
Dust-suppression equipment	Venturi wet-scrubber	Venturi wet-scrubber	Venturi wet-scrubber	Scroll cyclone	None	None	None	None
Hot-mix storage tonne	600	100	100	30	50	30	100	100

* from Boeing literature

TABLE 2

Summary of raw materials used

Raw materials		Locations							
Aggregate		Sparks Nevada	Arlington Washington	Shell Rock Iowa	Safford Arizona	Richardton/ Mott N. Dakota	Bismarck N. Dakota	Cameron Arizona	Prescott Arizona
Type	Coarse	Gravel	Gravel	Limestone	Gravel	Gravel	Gravel	Limestone	Gravel
	Fine	Gravel	Gravel	Gravel	Gravel	Gravel	Gravel	Gravel	Gravel
Sizes stocked	mm	25 – 10 10 – 3 5 – 0	20 – 0	20 – 0 5 – 0	3 sizes max. 20mm	20 – 14 14 – 0	20 – 14 14 – 0 5 – 2	20 – 10 10 – 2 5 – 0	20 – 0
Filler – type		Cement or lime	–	–	Cement	–	–	–	–
Bitumen grade		AR4000*	85–100 pen	85–100 pen	AR4000*	200–300 pen	85–100 pen	AR4000*	AR4000*

* AR4000: viscosity 4000 poises at 60°C (approximately equivalent to 85–100 pen)

TABLE 3

Outline of Joint Research Project on rotary drum mixers

Washington State Highway Department – Asphalt Paving Association of Washington Inc.

MODES OF OPERATION OF BOEING 600 PLANT	MIXING TEMPERATURES		PRODUCTION RATES – TONNES PER HOUR		
	80°C	135°C	LOW 250	MEDIUM –	HIGH 400–600

SAMPLING	COLD FEED	BINDER TANK	EXHAUST STACK	LORRY	PAVER	FINISHED PAVEMENT
LOCATION	COLD FEED	BINDER TANK	EXHAUST STACK	LORRY	PAVER	FINISHED PAVEMENT
NUMBER/ DAY	2	2	2	4	4	1 (Core)
TESTING PROGRAMME	Grading	Penetration	Volume of gases	←	Grading	→
	Sand equivalent	Thin-film oven test	Concentration and size of particles	←	Moisture	→
	Moisture		Concentration of hydrocarbons	←	Binder content	→
			Colour	←	Penetration of recovered binder	→
			Temperature	←	Cohesion	→
			Moisture	←	Stability	→
				←	Density	→
				Degree of coating	—	—

18. APPENDIX 1

DIARY OF VISIT TO USA, 1974

Date	Organisation/Location/Plant	Present
28 May	Chicago Testing Laboratories, Northbrook,Illinois	Conway Burton, President Ward K Parr, Vice-president
	Barber-Greene Company	F L Byerley, Vice-president Wes Beaty, General Marketing Manager Beau M Bunnell, Senior Development Engineer
29 May	Barber-Greene Company Aurora, Illinois	Wes Beaty Jim Tilman, Domestic Marketing Manager Fredric W Prill, Chief Engineer
	Production plant	
30 May	Iowa State Highway Commission Ames, Iowa	Bernie Ortgies, Materials Engineer Mike J Stump, Field Construction Engineer
	Barber-Greene Company	Wes Beaty and Jim Tilman
	Shellrock, Iowa Barber-Greene DM70 plant owned by Everds Brothers Construction	Harold Zimmerman, Plant Superintendent Dick Grimm (phone), Materials Quality Engineer
	Barber-Greene Company	Wes Beaty and Jim Tilman
	Laying site: County Road, S of Dumont, Iowa	
31 May	Shellrock, Iowa, Everds	Harold Zimmerman
	Barber-Greene Company	Jim Tilman
3 June	Boeing Construction Equipment Company, Renton, Washington	Peter Bailey, Director of Marketing Merle Korth, Regional Sales Manager
	Arlington, near Everett, Washington Boeing 600 plant owned by Associated Sand and Gravel	Gary Swanson, Plant Superintendent
	Boeing Construction	Merle Korth
	Road sites in Washington: (i) I 5 near Arlington (ii) State Route 532, Camano Island, near Everett. (iii) County road, Priest Point, Tulalip Indian Reservation, near Everett.	
	Washington State Highway Commission	T B Stone, Construction Engineer – Paving Rudi Larsen, Area Engineer
	Federal Highway Administration	John Coffee, Area Engineer Gary Nelson, Assistant
	Asphalt Institute	Bob Bridges, District Engineer
	Boeing Construction	Merle Korth
4 June	Boeing Construction Equipment Company, Renton, Washington	Peter Bailey and Merle Korth Jack Miller, Engineer – Pollution

Date	Organisation/location/plant	Present
5 June	Boeing Construction Equipment Production plant, Seattle, Washington	Merle Korth
	Road site: Port Ludlow, NE corner of Olympic Peninsular, Washington	Ron Terrell, Professor of Civil Engineering at University of Washington
	Boeing Construction	Merle Korth
6 June	Road site: Hartstene Island, near Olympia, Washington	
	Federal Highway Administration	John Coffee and Gary Nelson
	Boeing Construction	Merle Korth
	Washington State Highway Commission, Olympia, Washington	T B Stone Roger V LeClerc, Materials Engineer Dave Hause, Assistant Materials Engineer
	Federal Highway Administration	John Coffee and Gary Nelson
	Boeing Construction	Merle Korth
7 June	Sheraton – Renton Inn, Renton, Washington	
	Boeing Construction	Tim Shearer, Vice-president Merle Korth
10 June	Oregon State Highway Division Salem, Oregon	Caroll T Keasey, Construction Engineer James E Wilson, Assistant Engineer – Materials & Research John Walker
	Road site: State Route 211/224; Estacada to Eagle Creek, near Portland, Oregon.	Carroll Keasey, James Wilson and John Walker
11 June	Sparks, Reno, Nevada Boeing 600 plant owned by Robert Helms Construction Company	Plant operators
	Boeing Construction	Merle Korth
	Laying site: Nevada State Hospital, Sparks	
	Road site: City street, Reno, Nevada (outside Ryeland Medical Building)	
12 June	Nevada State Highway Department Carson City, Nevada	Henry C Prouty, Highway Engineer
	Boeing Construction	Merle Korth

Date	Organisation/Location/Plant	Present
13 June	Arizona State Highway Department Phoenix, Arizona	E F Sandlin, Assistant State Engineer – Construction Robert L Howard, Assistant Engineer – Quality Control
	Boeing Construction	Bill Harris, Sales Manager
	Safford, Arizona Boeing 400 plant owned by D C Speers Ltd.	Plant operators
	Arizona State Highway Dept.	Robert Howard Jim McGee, Assistant District Engineer Larry Richards, Administrative Assistant
	Boeing Construction	Bill Harris
	Laying site: US Highway 70 Thatcher, Arizona	Robert Howard, Jim McGee and Larry Richards
	Boeing Construction	Bill Harris
	District Highway Headquarters and Laboratory, Safford, Arizona	Owen Ford, District Highway Engineer Robert Howard, Jim McGee and Larry Richards
	Boeing Construction	Bill Harris
14 June	Prescott, Arizona Boeing 80 plant owned by Mettler Company	Dick Kruger, Plant Manager
	Boeing Construction	Bill Harris
	Cameron, Arizona. Boeing 100 plant owned by Northern Improvement Company	Plant operators
	Boeing Construction	Bill Harris
17 June	Minnesota State Highway Dept. St Paul, Minnesota	Ed Heinan, Assistant Commissioner Blaine Himmelman, Materials Engineer Pat Hughes, Bituminous Engineer
	Minnesota Pavement Association	Dave Holt, (formerly State Materials Engineer)
18 June	Northern Improvement Company Fargo, North Dakota	Steve McCormick, Manager Ernie Luer, District Superintendent
19 June	North Dakota Highway Department Bismarck, North Dakota	R E Bradley, Chief Engineer Erling Henrikson, Construction Engineer Reuben Reich, Materials Engineer
	Richardton/Mott, North Dakota Boeing 400 plant owned by Meyer Construction	Plant operators
	N. Dakota Highways Dept.	Erling Henrikson and Reuben Reich
	Laying site: State Route 8, Mott, North Dakota	Erling Henrikson and Reuben Reich

Date	Organisation/Location/Plant	Present
20 June	Bismarck, North Dakota Boeing 100 plant owned by Northern Improvement Company	Plant operators Erling Henrikson and Reuben Reich
	Laying site: Car park, Bismarck, North Dakota	Erling Henrikson and Reuben Reich
21 June	Federal Highway Administration Washington, D.C.	H L Anderson, Director, Office of Development C F Scheffey, Director, Office of Research Criswell, Chief of Implementation Division Edwin C Granley, Highway Engineer, Implementation Division G Denny, Office of Highway Operations J Carroll, Office of Highway Operations
	National Asphalt Pavement Association	Charles R Foster, Director of Engineering and Research

19. APPENDIX 2

EXTRACTS FROM STATE SPECIFICATIONS

The following are extracts from six different State Specifications. They have been selected as being the most explicit in describing the precise requirements for both the process and the materials produced.

19.1 Stockpiling of aggregate

'Prior to being fed into the dryer, the aggregate shall be separated into two general sizes. Separation shall be on a ½" square sieve, or on a ½" slotted sieve having a slot length (1" maximum) which will not permit passage of material that would be retained by a square sieve opening equivalent to the maximum size of aggregate specified in the contract. The material retained on the ½" square or slotted sieve shall be crushed to meet the maximum size specified in the contract. The material passing that sieve shall be placed in a separate stockpile.'

'If aggregate gradations indicate an advantage by splitting on a screen size differing from the specified ½", it may be changed to a smaller size at the discretion of the Engineer.'

'No less than 30 percent of the total volume or tonnage of aggregate being separated shall be placed in each of the two stockpiles.'

19.2 Grading of stockpiled aggregate

'When a representative volume of material has been produced, the Engineer will determine the average percentage of material passing the No.4 sieve in each stockpile. This average percentage will be established as a target value to be maintained within a tolerance of ± 5 per cent for the remainder of the aggregate produced from that aggregate source.'

19.3 Handling of aggregate

'When cold feed control equipment is used in the work, each portion of the material shall be stored separately. Placing the separated aggregate into storage or moving the aggregate from storage to feeder shall be accomplished by any method which will not cause segregation, degradation or combinations of aggregate which fail to meet the specified requirements.'

19.4 Rejection of oversize aggregate

'If plant screens are eliminated as hereinafter permitted, the contractor shall install in the feeder mechanism ahead of the mixer such vibratory screens or other suitable devices which will reject stones larger than 1" and eliminate lumps of aggregates which have become cemented together.'

19.5 Aggregate proportioning

'The plant shall include a means for accurately proportioning each size of aggregate prior to the drying operation.

The plant shall have a mechanical feeder mounted under each compartment bin. Each compartment bin shall have an accurately controlled individual gate for volumetrically measuring the material drawn from each compartment. The feeding orifice shall be rectangular with one dimension adjustable by positive means Indicators shall be provided for each gate to show the respective gate opening.

A meter for determining the rate of each feeder, or a revolution counter, shall be provided.'

19.6 Filler proportioning

'Commercial filler material introduced into the mixer shall be drawn from storage bins by a continuous mechanical feeder which will uniformly feed the mixer within ten (10) per cent of the required amount.'

19.7 Monitoring of aggregate flow rate

'When drum-mixing plants are used, the central conveyor shall be equipped with a continuous weighing system with a recorder that can be monitored by the plant operator.'

19.8 Bitumen proportioning

'Bitumen Metering Device. The bituminous material shall be introduced into the mixer through a gallonage meter by a positive displacement metering device. This metering device shall be equipped with a ready means of varying the bituminous material delivery rate.'

19.9 Interlock of aggregate and bitumen flow rates

'The asphalt control unit shall be interlocked with the aggregate weighing system and shall be equipped to automatically adjust for variation in aggregate delivery. Except when approved by the engineer in writing, the plant shall be operated with automatic controls. The asphalt control unit shall be equipped so the plant operator can monitor and adjust the flow rate of aggregate or asphalt.'

'The system shall be interlocked in a manner that will stop all feed components if either the aggregate or asphalt feed stops.'

19.10 Processing in the mixing drum

'The heating, coating, and mixing of the bituminous mix shall be accomplished in an approved parallel flow drier-mixer. The aggregate and asphalt shall enter the drum at the same end the burner is located and travel parallel to the flame and exhaust air stream. Heating shall be controlled to prevent injury to the aggregate or the bitumen. The system shall be equipped with automatic burner controls and shall provide for temperature sensing of the bituminous mixture at the discharge.'

19.11 Mixed material requirements

'After the required amounts of aggregate and bitumen have been introduced into the mixer, the materials shall be mixed until a uniform and complete coating of the particles and a thorough distribution of the bitumen throughout the mixture is secured. This requirement must be satisfied through control of the temperature and moisture content in the mixture, and rate of plant production.'

'The moisture content of the bituminous mixture at discharge from the mixer shall not exceed 3 per cent.'

'The temperature of the bituminous mixture at discharge from the mixer shall not exceed 300°F. The temperature of the mix at laydown shall be not less than 180°F. The actual mixing temperature shall be adjusted as directed by the Engineer, within the allowable limitations, to best suit construction conditions.'

'The compaction of the mixture will be accepted in lot sizes equal to the number of tons placed each production day. The density of the pavement will be monitored and determined by means of a portable nuclear test device, or other approved methods. A test will be run at a randomly determined location within each sublot equal to approximately 1,200 square yards of pavement and the results will be made immediately available to the contractor.'

20. APPENDIX 3

BIBLIOGRAPHY OF SELECTED ARTICLES

20.1 Reports on early work in Washington

Descriptions are given of the projects carried out at Port Ludlow and Hartstene Island during 1970 and 1971. The later papers also include some supplementary information about other work.

20.1.1 ALLEN W L Jr and J T PRICE. The dryer-drum mixing process for producing asphalt concrete mixtures in the State of Washington. *Western Association of State Highway Officials, 51st Annual Meeting, Salt Lake City, Utah, 5–9th June 1972,* pp29.

20.1.2 TERREL R L. A new process for the manufacture of asphalt paving mixtures. *III Inter-American Conference on Materials Technology, Rio de Janeiro, Brazil, 14–17th August 1972,* pp26.

20.1.3 TERRELL R L and E S RICHARDSON. Asphalt paving mixtures produced by the dryer-drum process. *Federal Highway Administration, Washington Division, Final Report.* Olympia, Washington, 1972 (Federal Highway Administration, Washington Division).

20.1.4 TERREL R L. A new process for the manufacture of asphalt paving mixtures. *Twenty-Second Annual Arizona Conference on Roads and Streets, Tucson, Arizona, 12–13th April 1973,* pp19.

20.1.5 KASTNER W W, R L TERREL and P B COWAN. Current progress in the development of a rotary drum mixer system. Unpublished paper. *Western Summer Meeting, Highway Research Board, Olympia, Washington, August 1973,* pp21.

20.2 A report on early work in Iowa.

A description is given of the operation of a McConnaughay-designed plant during 1970 and 1971.

20.2.1 ZIEGLER J L. The turbulent mass process. *National Asphalt Pavement Association, 17th Annual Convention, 4–14th January 1972,* 27–37.

20.3 Experiences of Oregon State Highway Division

Both papers describe the Eagle Creek-Estacada project carried out during 1972. The second paper also covers the Narrow-Valley Falls project carried out during 1973.

20.3.1 KEASEY C T. Asphalt concrete production by the dryer-drum mixer process in Oregon. *Western Association of State Highway Officials, 52nd Annual Meeting, Helena, Montana, June 1973,* pp23.

20.3.2 WILSON J E Jr. The dryer drum process for producing bituminous concrete mixes. *Northwest Roads and Streets Conference, Corvallis, Oregon, February 1974,* pp49.

20.4 Experiences of North Dakota Highway Department

20.4.1 REICH R. North Dakota Experience with drum-dryer mixing. *13th Annual Idaho Asphalt Conference, University of Idaho, 10th November 1972,* pp9.

20.4.2 HAAS S. Drum-dryer mixing in North Dakota. Unpublished paper. *Annual Meeting of the Association of Asphalt Paving Technologists, Williamsburg, Virginia, 25–27th February 1974,* pp17.

20.5 Evaluation studies by the Federal Highway Administration

Descriptions are given of three studies carried out in North Dakota, Iowa and Minnesota during 1972. The two papers are complementary with the first giving a considerable amount of test data.

20.5.1 GRANLEY E C. The dryer drum process for producing bituminous concrete mixes. *American Association of State Highway Officials, 58th Annual Meeting, Phoenix, Arizona, 28th November 1972,* pp21.

20.5.2 GRANLEY E C and R E OLSEN. Progress report on dryer drum process for producing bituminous concrete mixes. *Publ. Rds,* 1973, *37* (6), 205–10.

20.6 Views of the Federal Highway Administration in 1974

20.6.1 GRANLEY E C. State-of-the-art dryer drum process. *Implementation Division, Office of Development, Federal Highway Administration,* Unpublished Report. Washington D C, 1974 (Federal Highway Administration).

20.7 Views of the National Asphalt Pavement Association

20.7.1 FOSTER C R. Tests on mix made in asphalt plant where mixing was accomplished in the dryer. *National Asphalt Pavement Association News,* 1970, (October), 4–5.

20.7.2 FOSTER C R. More on drum-mixing. *National Asphalt Pavement Association News,* 1972, (September).

20.7.3 FOSTER C R and F KLOIBER. Supplement to more on drum-mixing. *National Asphalt Pavement Association News,* 1973, (January).

20.7.4 FOSTER C R. Reassessing drum-mixers. *National Asphalt Pavement Association News,* 1974, (December).

20.8 Laboratory studies of the drum-mixing process

20.8.1 BEATY R W and B M BUNNELL. The manufacture of asphalt concrete mixtures in the dryer drum. *Canadian Technical Asphalt Association, Annual Meeting, Quebec City, Quebec, 19–21st November 1973,* pp42.

20.8.2 PARR W K. Study of drum-mixing coarse bituminous macadam mixtures. *Barber-Greene Company.* Unpublished Technical Report 51071. Northbrook, Illinois, 1973 (Chicago Testing Laboratory, Inc.).

21. APPENDIX 4

EMISSION REQUIREMENTS IN THE UK AND THE USA

21.1 Position in the UK – 1974

Until recently the emissions from bituminous mixing plants have not been subject to any generally effective surveillance and, as a consequence, the control of the quantity of particulate matter that has been discharged into the atmosphere has been somewhat variable. In 1971 the emissions from mineral works were brought under the control of the 'Clean Air and Alkali Inspectorate', of the Department of the Environment, who proposed that, for the present, the UK should base its requirements on the use of the 'Best Practicable Means' for the removal of particulate matter from the exhaust gases before discharge into the atmosphere. Appendix VII of the 1973 Annual Report of the Inspectorate has further clarified the position by recommending limits for acceptable emission levels. These may be summarised as limiting the emission of total particulate matter to 460 mg/m^3 of moist gas, when measured under standard conditions of temperature and pressure, where the rate of gas discharged does not exceed 700 m^3/min; this emission limit for particulate matter is reduced, on a linear scale, down to 230 mg/m^3 when the gas discharge rate is 1400 m^3/min. For gas discharge rates higher than 1400 m^3/min the limit remains at 230 mg/m^3. These limits are only issued as guide lines and are subject to revision in the light of experience.

21.2 Position in the USA – 1974

A very similar situation has arisen in the USA where the 'Clean Air Act' of 1970 set up the Environmental Protection Agency (EPA) with the object of establishing Federal standards for plant emissions. At present the position is rather fluid with most of the States setting up their own standards which average out at 290 mg/m^3. Nevertheless, in February 1974 the EPA proposed a limit of 90 mg/m^3 when the gas volume is calculated on a dry basis. There is also an opacity requirement of less than 20 per cent. An article by Fred Kloiber in a NAPA News issued in May 1974 discusses these proposals more fully; the title of the article is: 'New Source Performance Standards for Asphalt Concrete Plants'.

The overall impression gained during the visit was that the emissions were not yet being checked on a large scale. The usual practice would appear to be that a local inspector would make a visual spot assessment of the acceptability, or otherwise, of the plant emissions with a particular emphasis on the opacity. This situation is probably a direct reflection of the shortage of trained personnel to handle the equipment required to carry out quantitative checks on the particulate emissions. The local attitude seemed also to depend upon the environment in which the plant was located; this, of course, tends to be the case in the UK.

22. APPENDIX 5

LIST OF PLATES

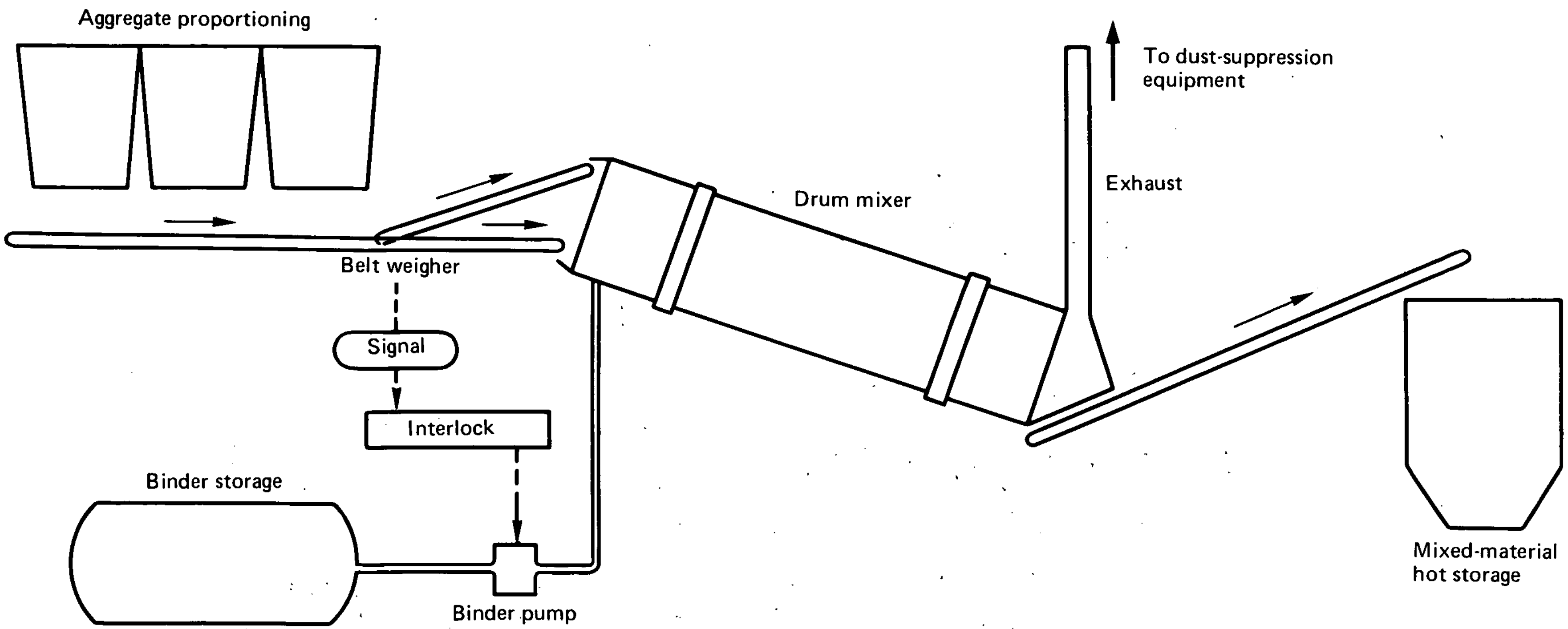


Fig. 1 OUTLINE DIAGRAM OF PLANT AND PROCESS

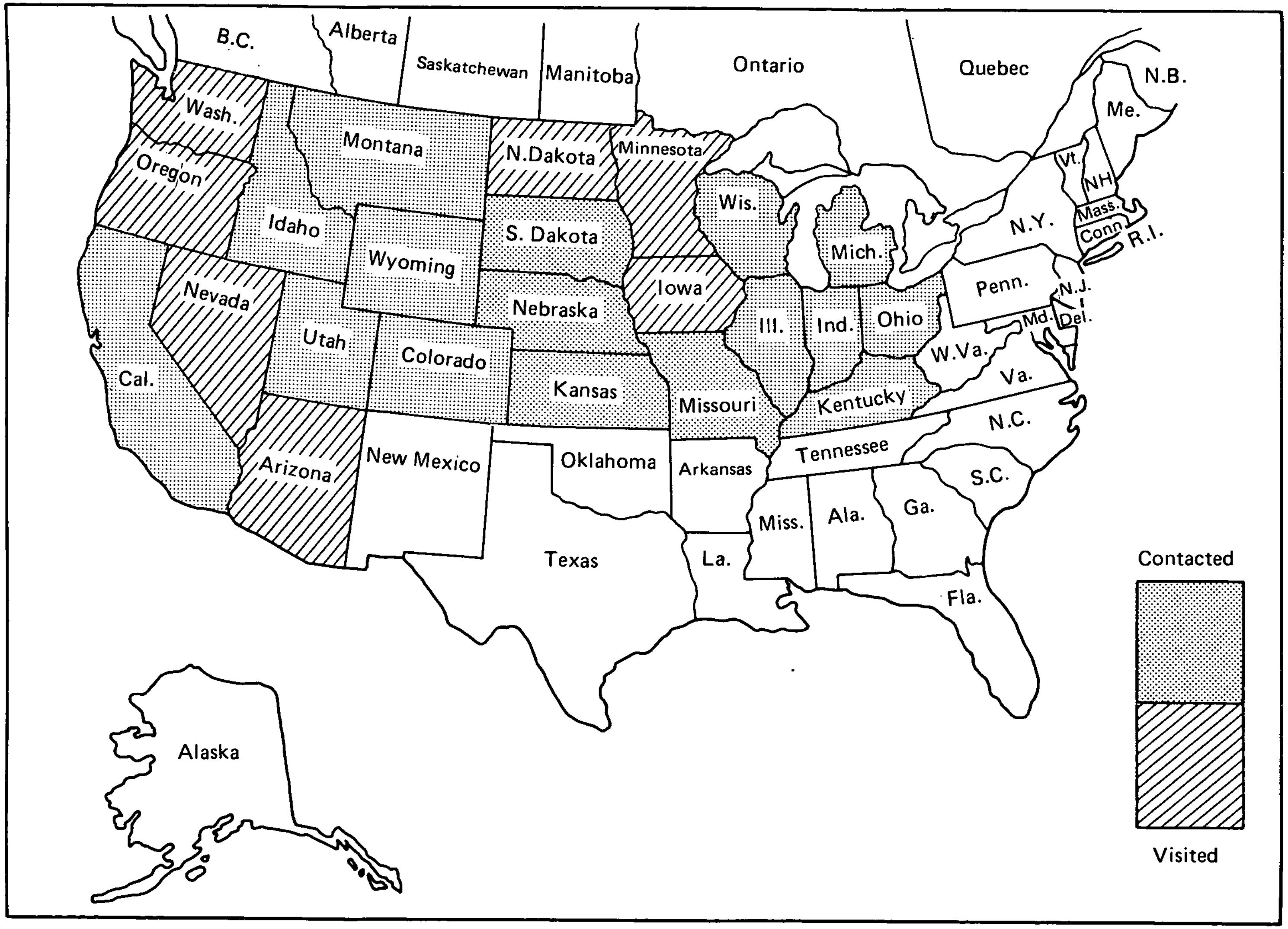
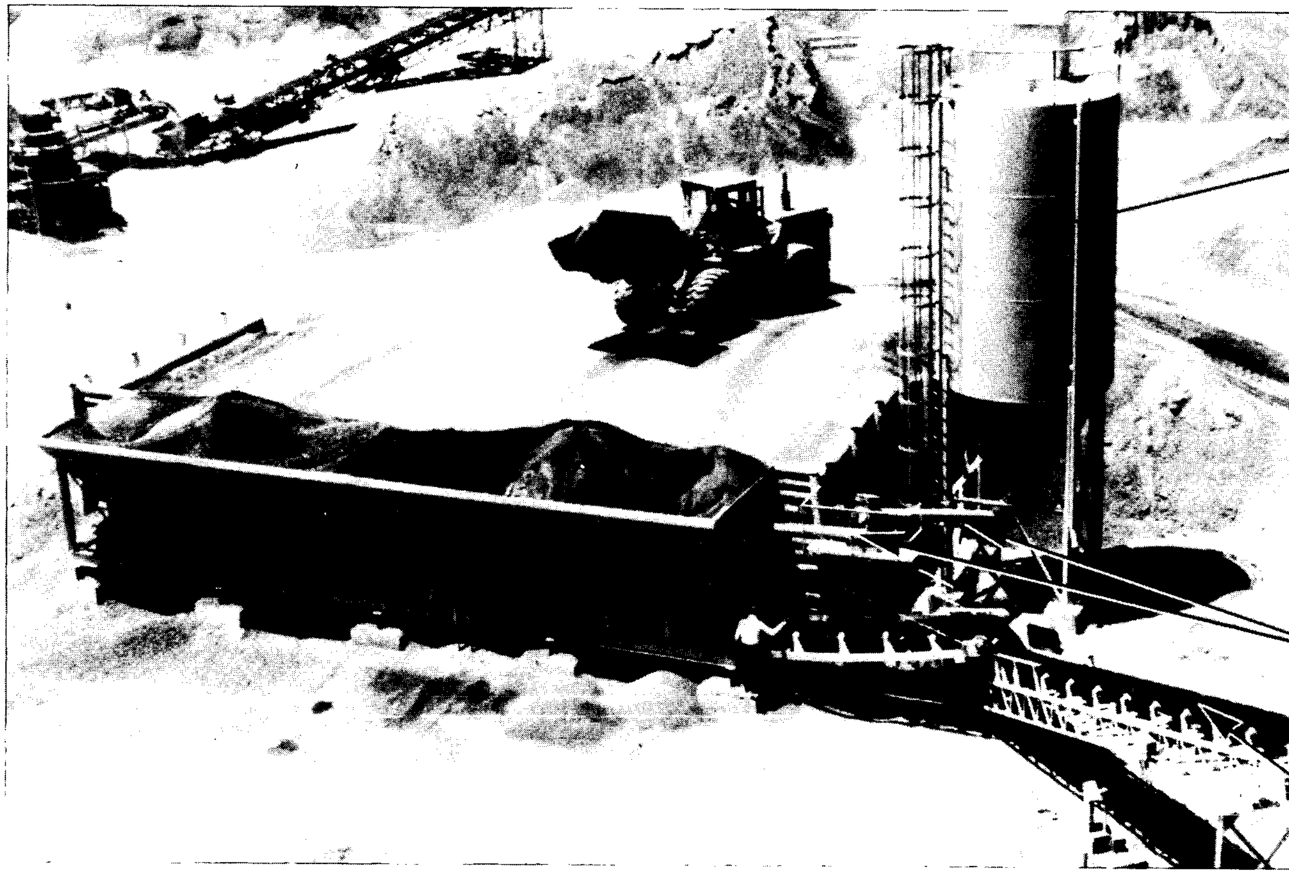


Fig. 2 STATES VISITED AND CONTACTED

Neg. no. R719/75/13

PLATE 1
THREE-BIN COLD-AGGREGATE PROPORTIONER UNIT AND FILLER ADDITION POINT SAFFORD, ARIZONA



Neg. no. R719/75/35

PLATE 2
FOUR-BIN COLD–AGGREGATE PROPORTIONING UNIT AND FILLER SYSTEM
SPARKS, NEVADA

Neg. no. R775/75/2

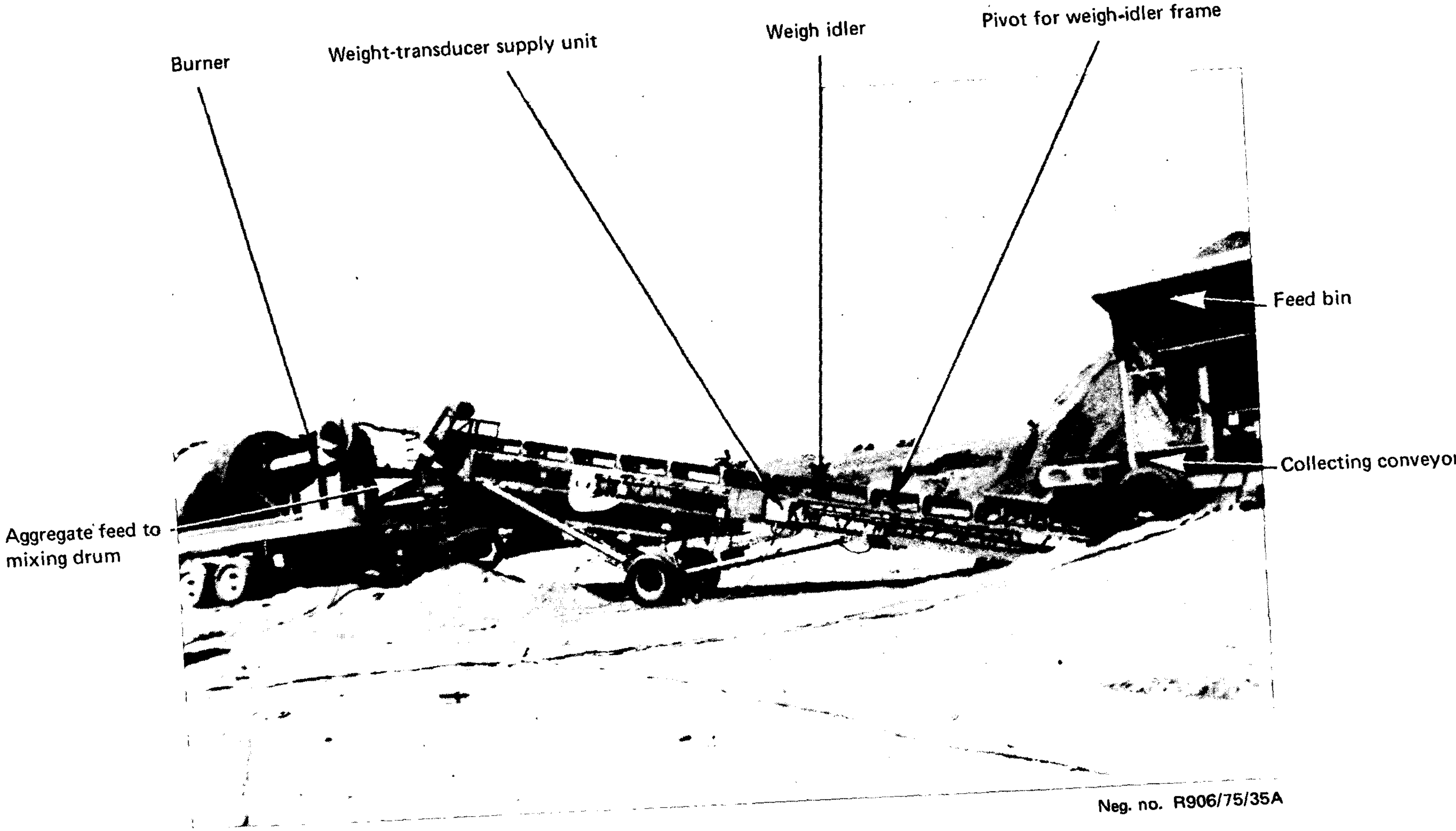
PLATE 3

COLD–AGGREGATE PROPORTIONER
ARLINGTON, WASHINGTON

Neg. no. R719/75/33

PLATE 4

BELT WEIGHER FITTED ON TRANSFER CONVEYOR TO MIXING DRUM
ARLINGTON, WASHINGTON



Neg. no. R906/75/35A

PLATE 5
BELT WEIGHER FITTED ON TRANSFER CONVEYOR AND AGGREGATE FEED BELOW BURNER
RICHARDTON–MOTT, NORTH DAKOTA

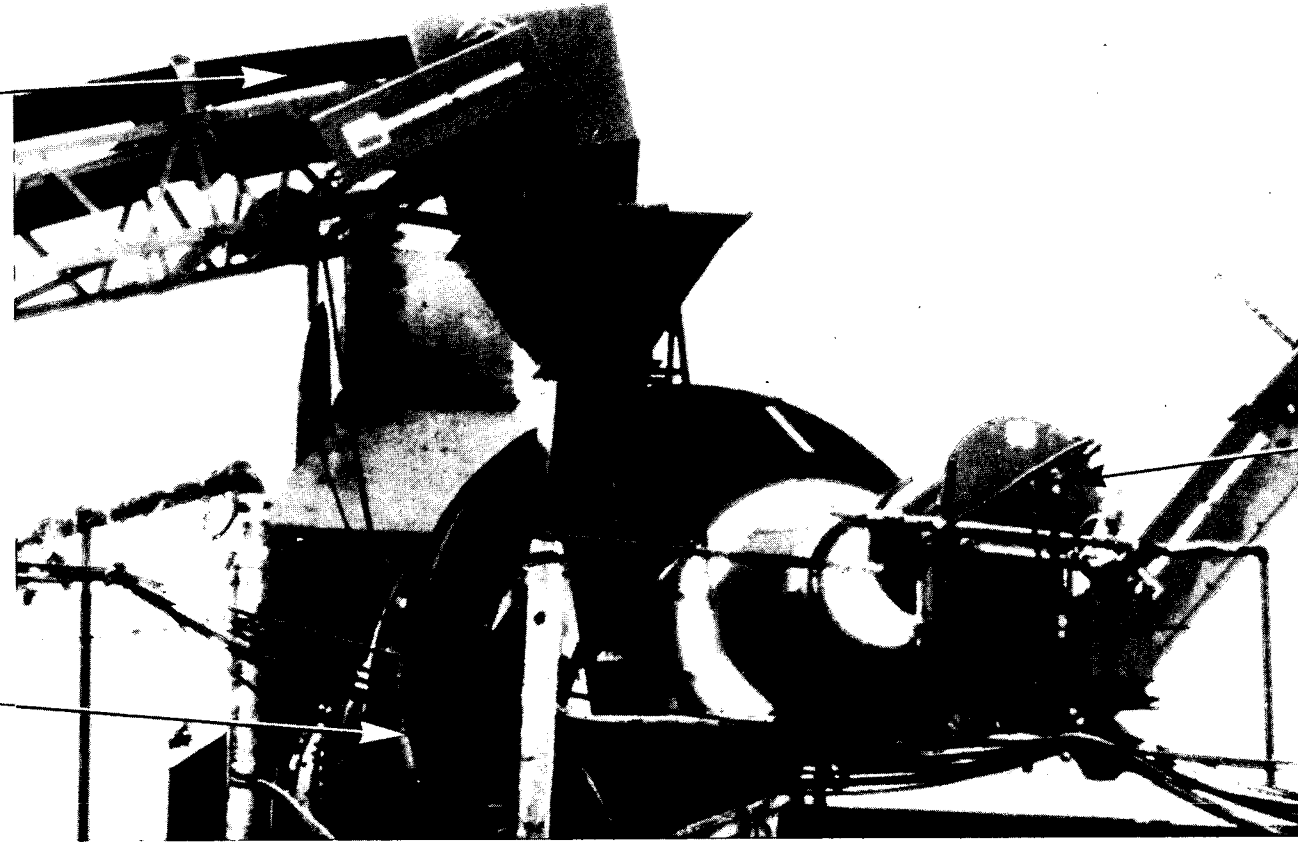
Neg. no. R906/75/29A

PLATE 6

REVERSED DISCHARGE FROM BIN WHEN INTEGRAL BELT WEIGHER FITTED BISMARCK, NORTH DAKOTA

Neg. no. R719/75/36A

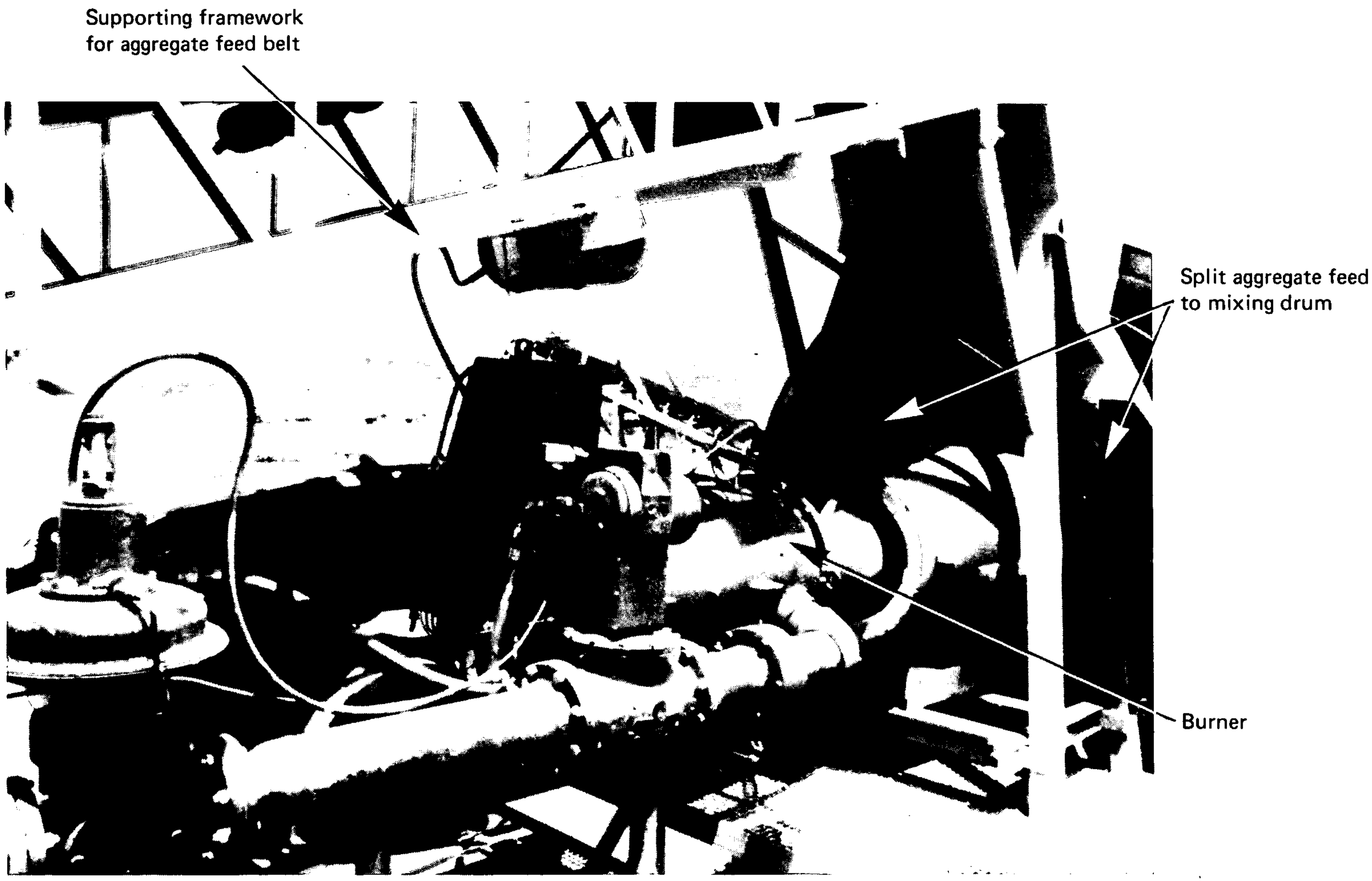
PLATE 7
MIXING DRUM, SCROLL CYCLONE AND DUST–RETURN SYSTEM
SAFFORD, ARIZONA



Neg. no. R719/75/3

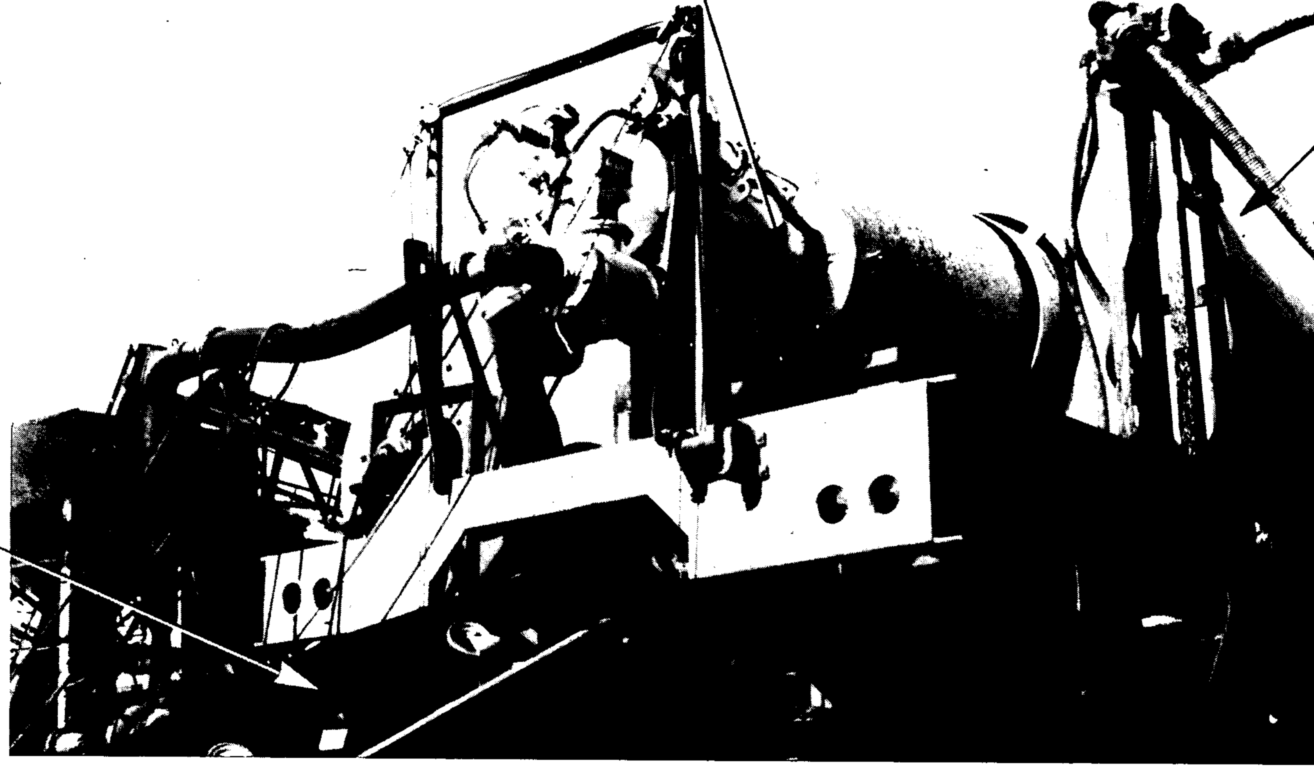
PLATE 8

AGGREGATE FEED BESIDE OFFSET BURNER
SHELL ROCK, IOWA



Neg. no. R775/75/16

PLATE 9
AGGREGATE FEED BOTH SIDES OF BURNER
SPARKS, NEVADA



Neg. no. R906/75/28A

PLATE 10
AGGREGATE FEED BELOW BURNER
BISMARCK, NORTH DAKOTA

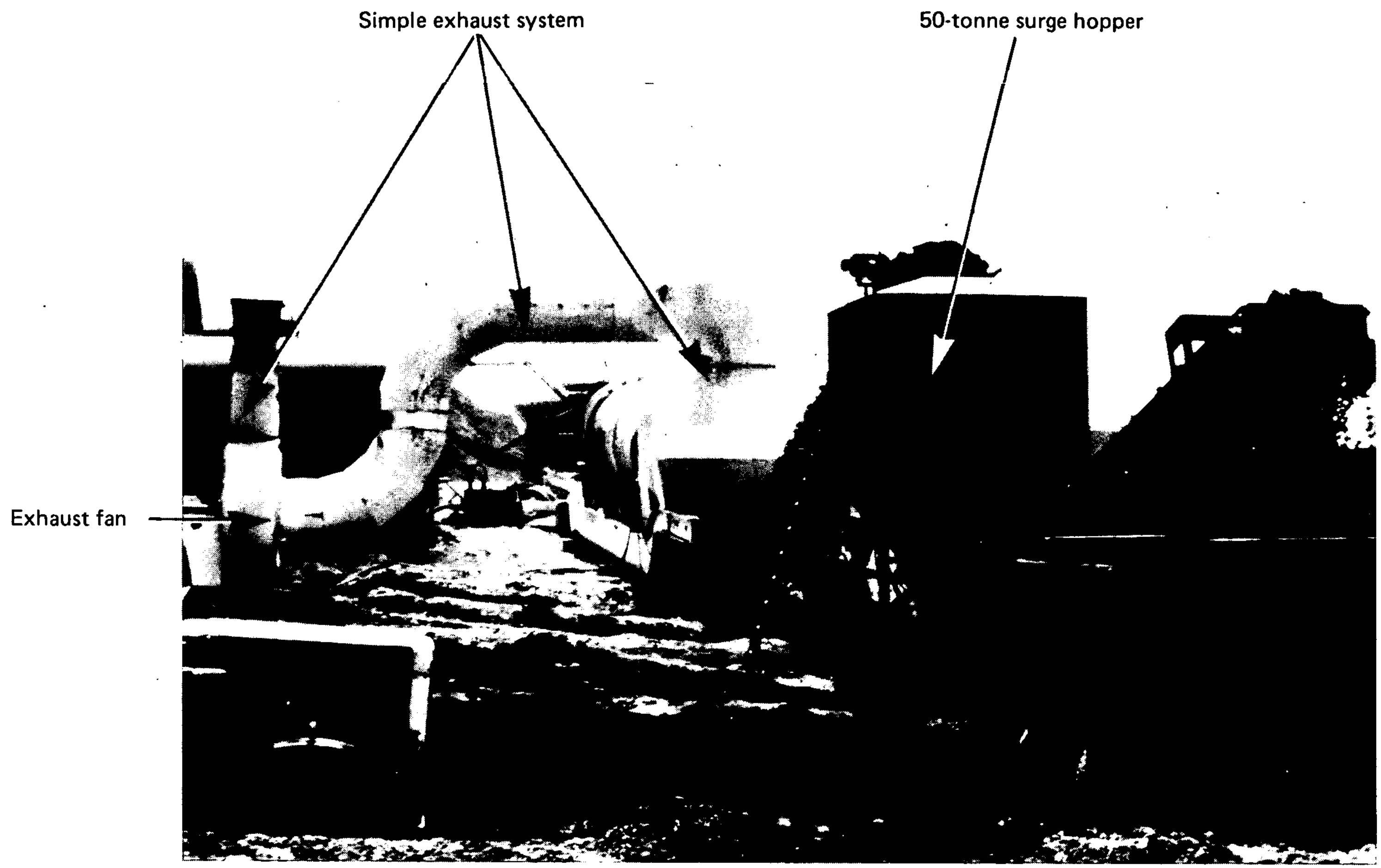


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PLATE 11

MIXED–MATERIAL SURGE HOPPER AND EXHAUST SYSTEM
RICHARDTON–MOTT, NORTH DAKOTA

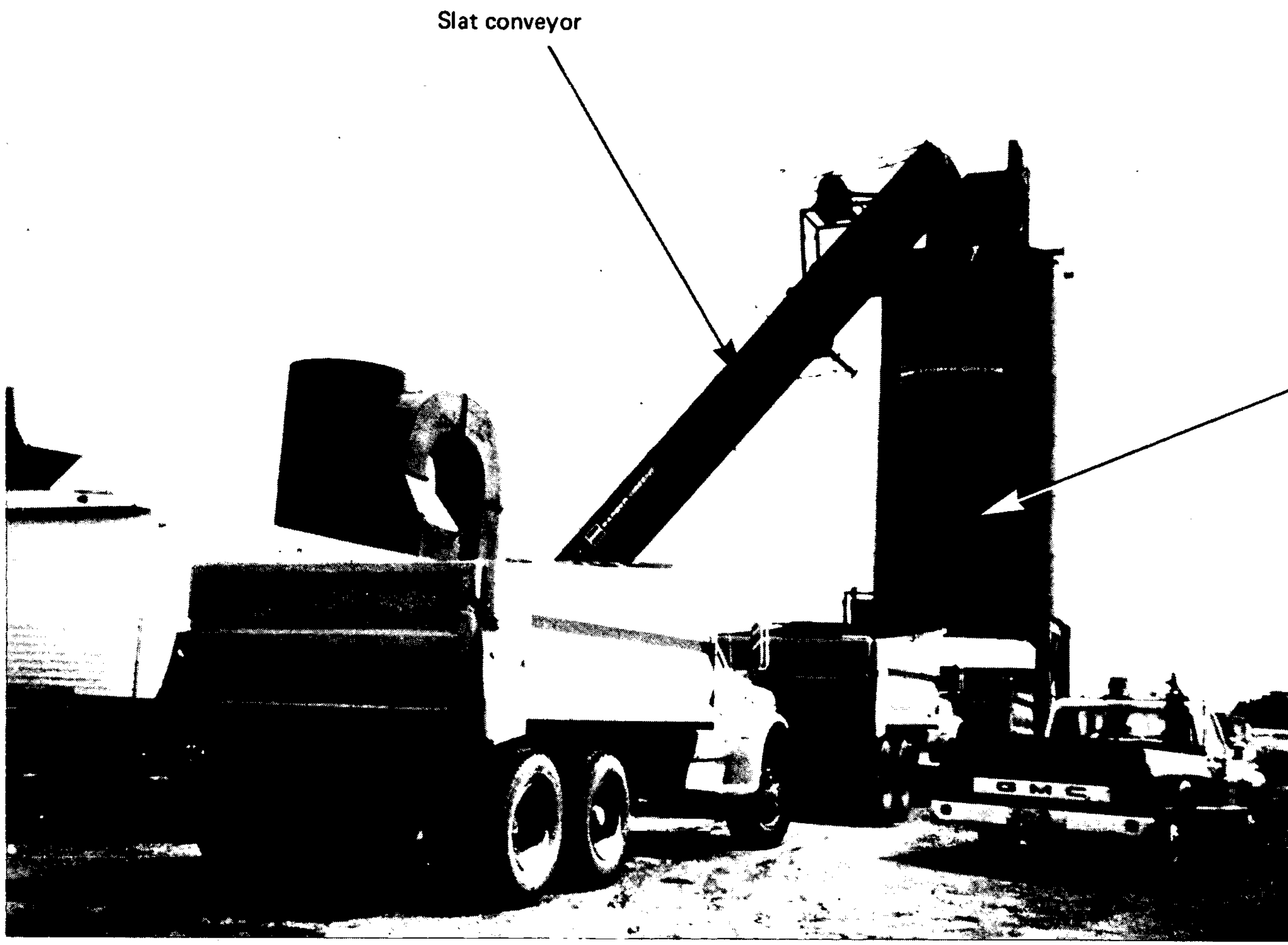

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PLATE 12
MIXED–MATERIAL STORAGE SILO
SHELL ROCK, IOWA

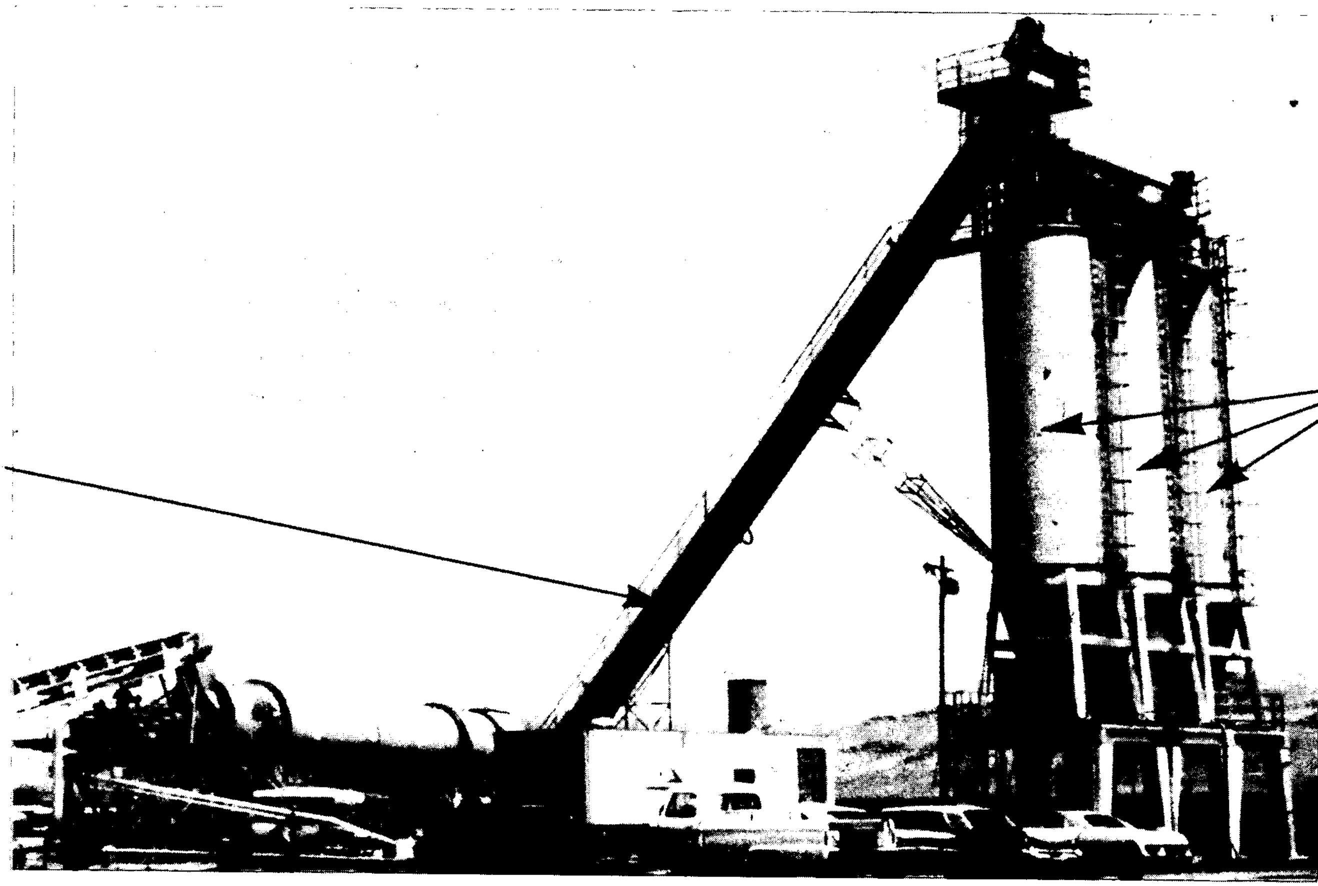

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PLATE 13
MIXED-MATERIAL STORAGE SILOS
SPARKS, NEVADA

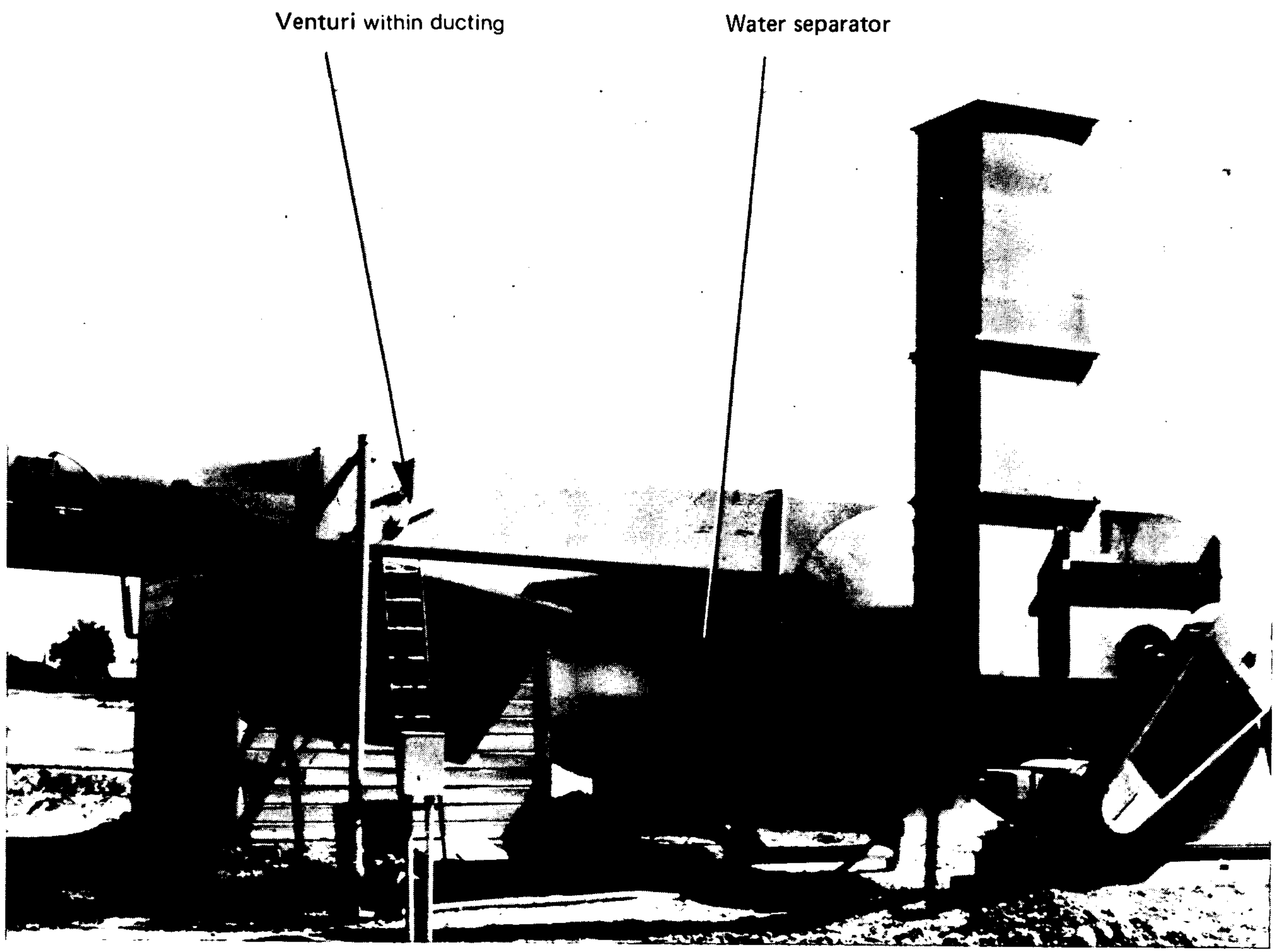

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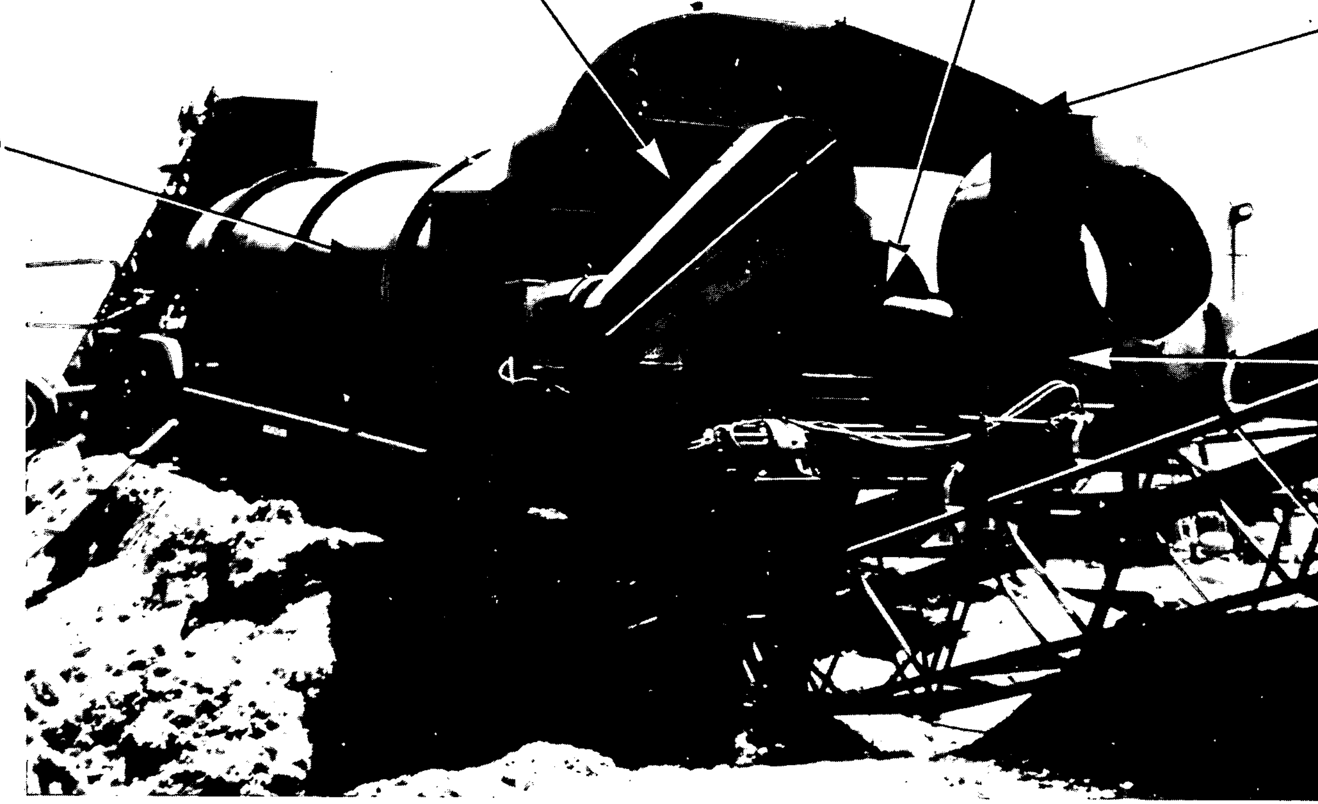
PLATE 14
VENTURI WET–SCRUBBER, WATER SEPARATOR AND EXHAUST FAN
SPARKS, NEVADA



Neg. no. R737/75/5

PLATE 15
SCROLL CYCLONE
SAFFORD, ARIZONA

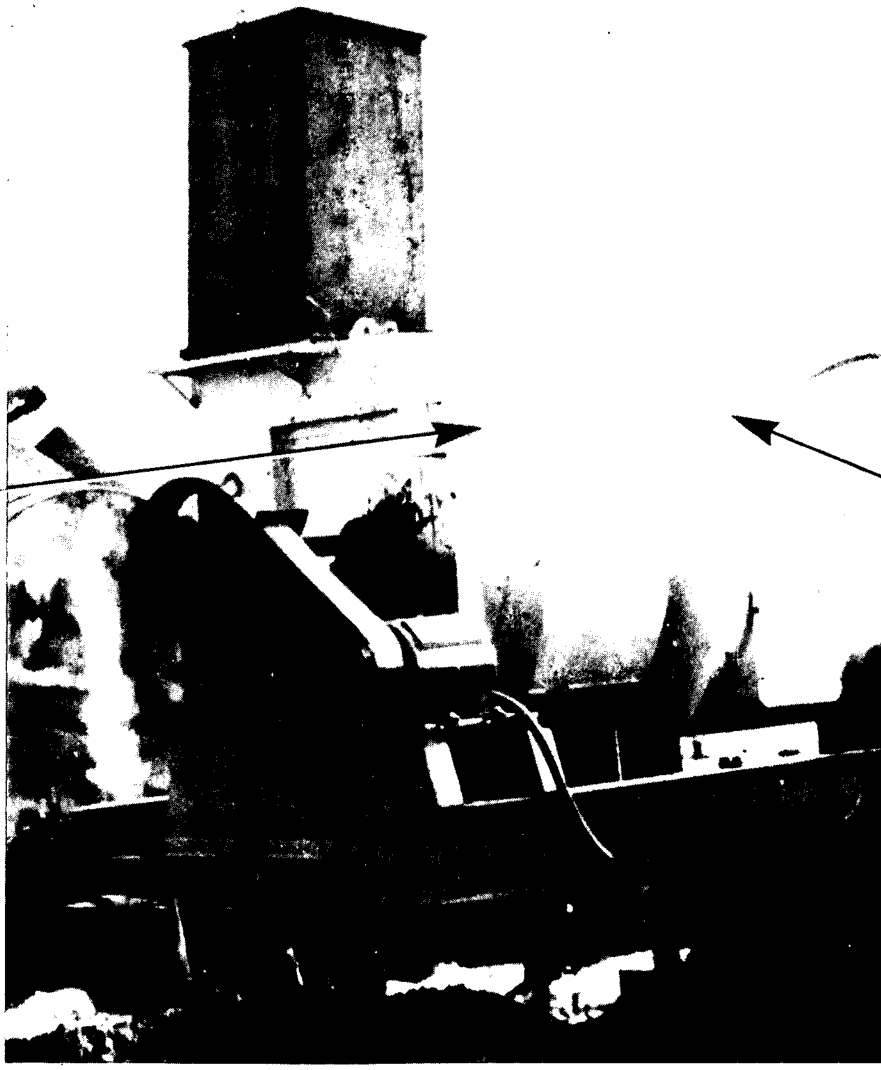


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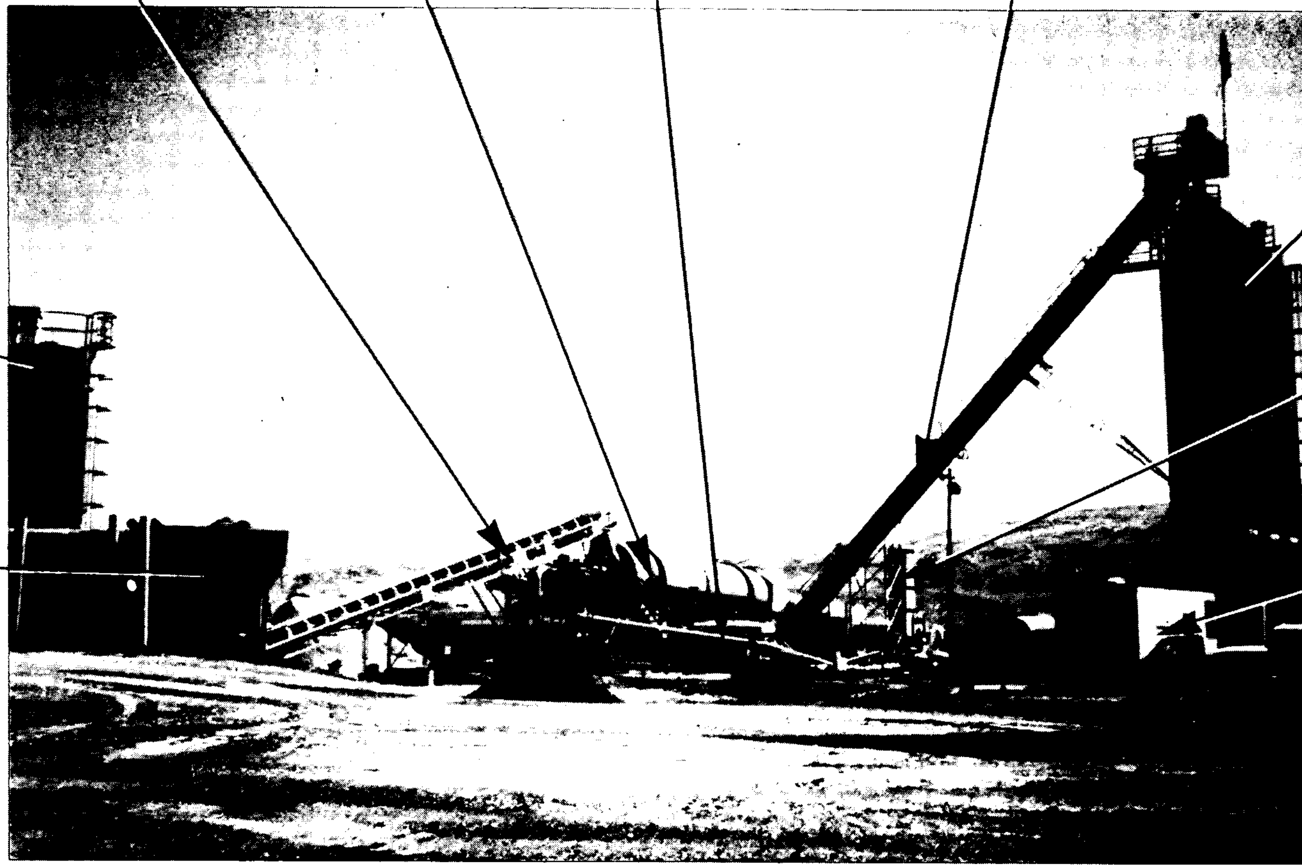
PLATE 16
SIMPLE EXHAUST SYSTEM
BISMARCK, NORTH DAKOTA

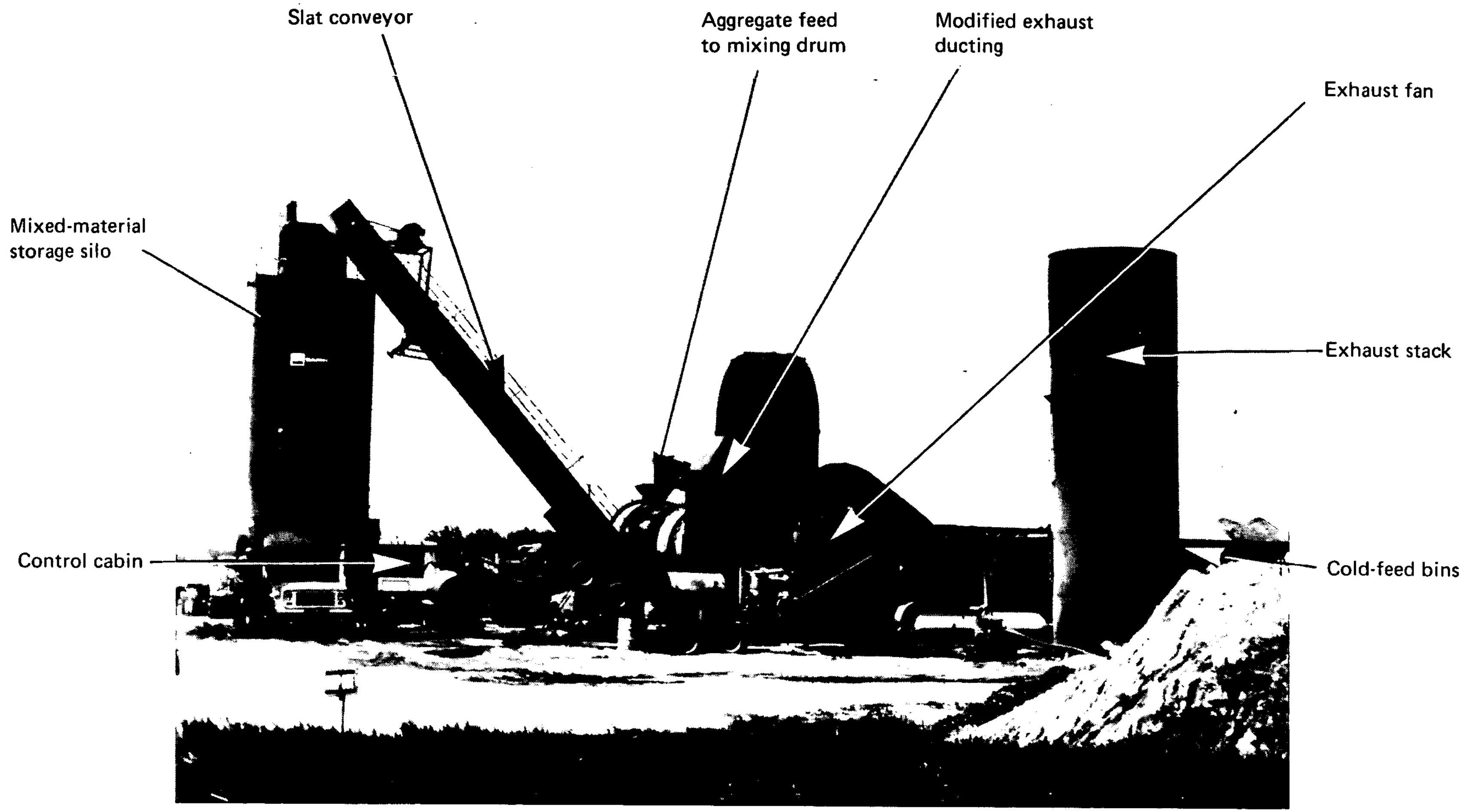


Neg. no. R720/75/28

PLATE 17
GENERAL VIEW OF BOEING MODEL 600 PLANT
SPARKS, NEVADA

Neg. no. R775/75/13

PLATE 18
GENERAL VIEW OF BOEING MODEL 600 PLANT
ARLINGTON, WASHINGTON



Neg. no. R775/75/5

PLATE, 19
GENERAL VIEW OF BARBER–GREENE MODEL DM70 PLANT
SHELL ROCK, IOWA

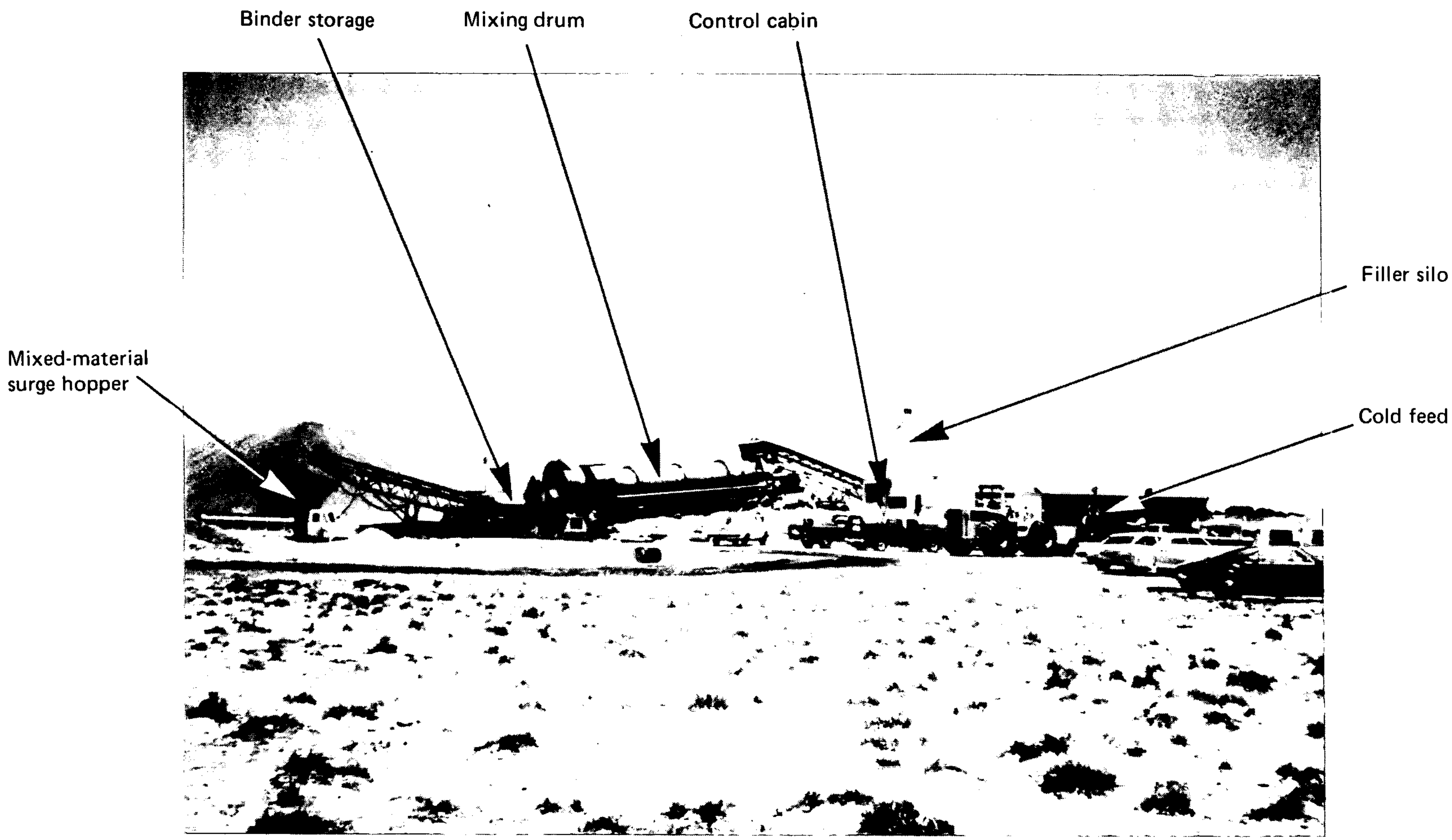


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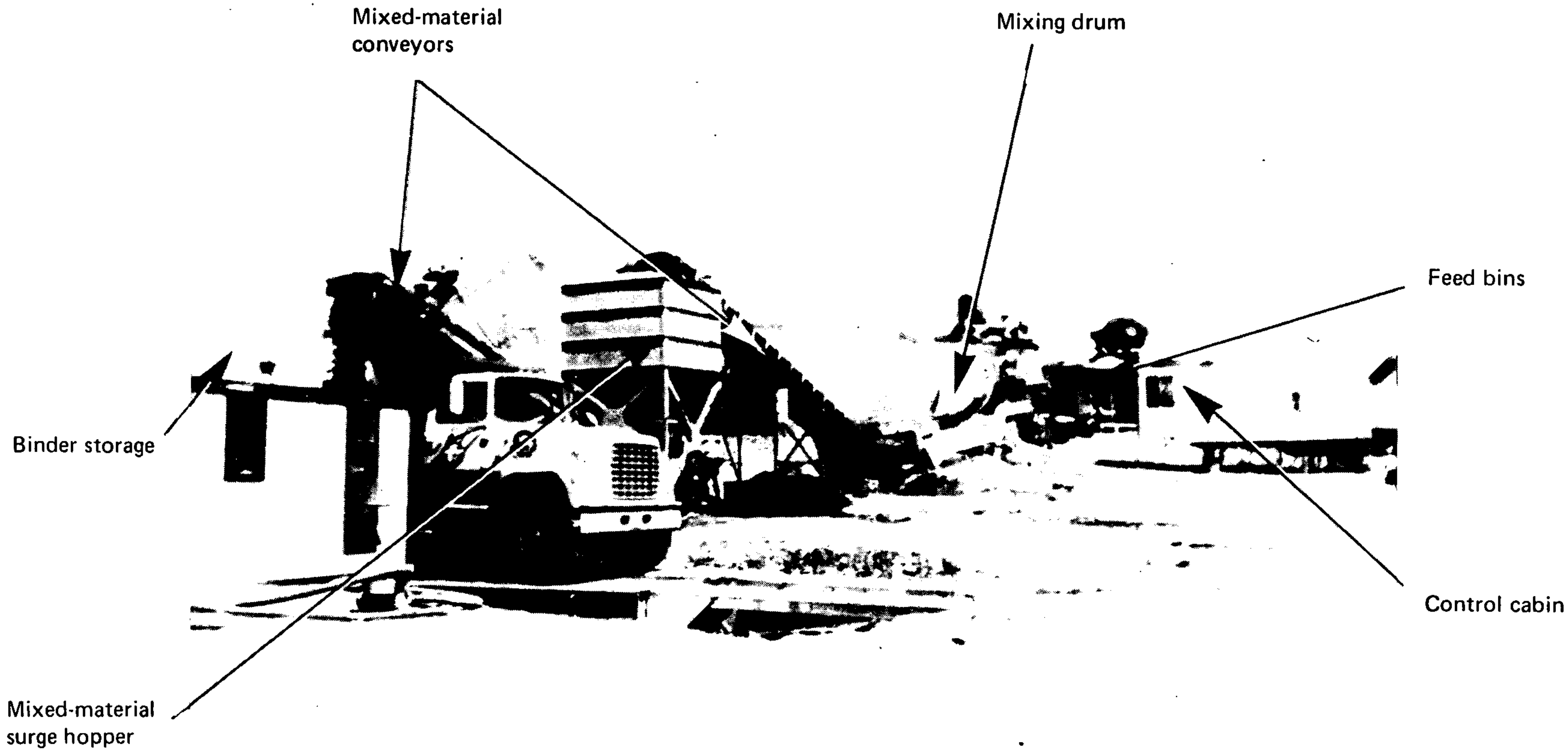
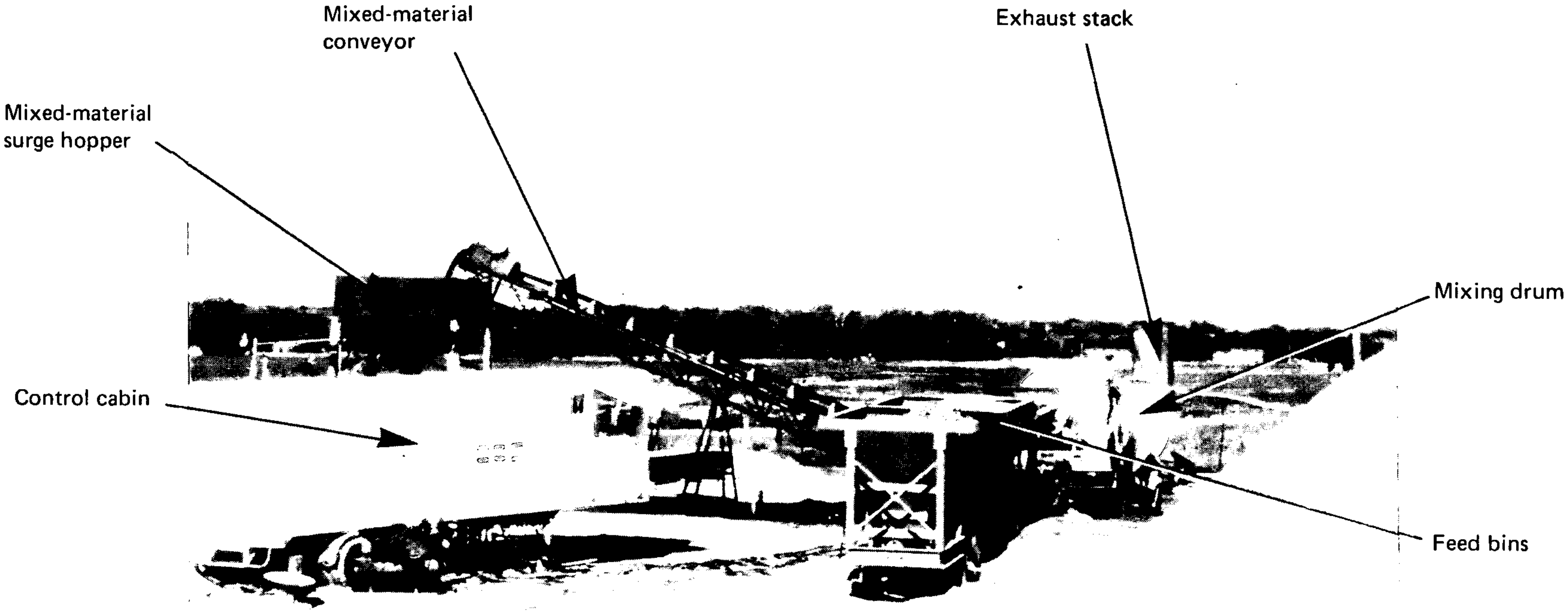
PLATE 20
GENERAL VIEW OF BOEING MODEL 400 PLANT
SAFFORD, ARIZONA



Neg. no. R906/75/26A

PLATE 21
GENERAL VIEW OF BOEING MODEL 400 PLANT
RICHARDTON–MOTT, NORTH DAKOTA



Neg. no. R775/75/36A

PLATE 22
GENERAL VIEW OF BOEING MODEL 100 PLANT
BISMARCK, NORTH DAKOTA

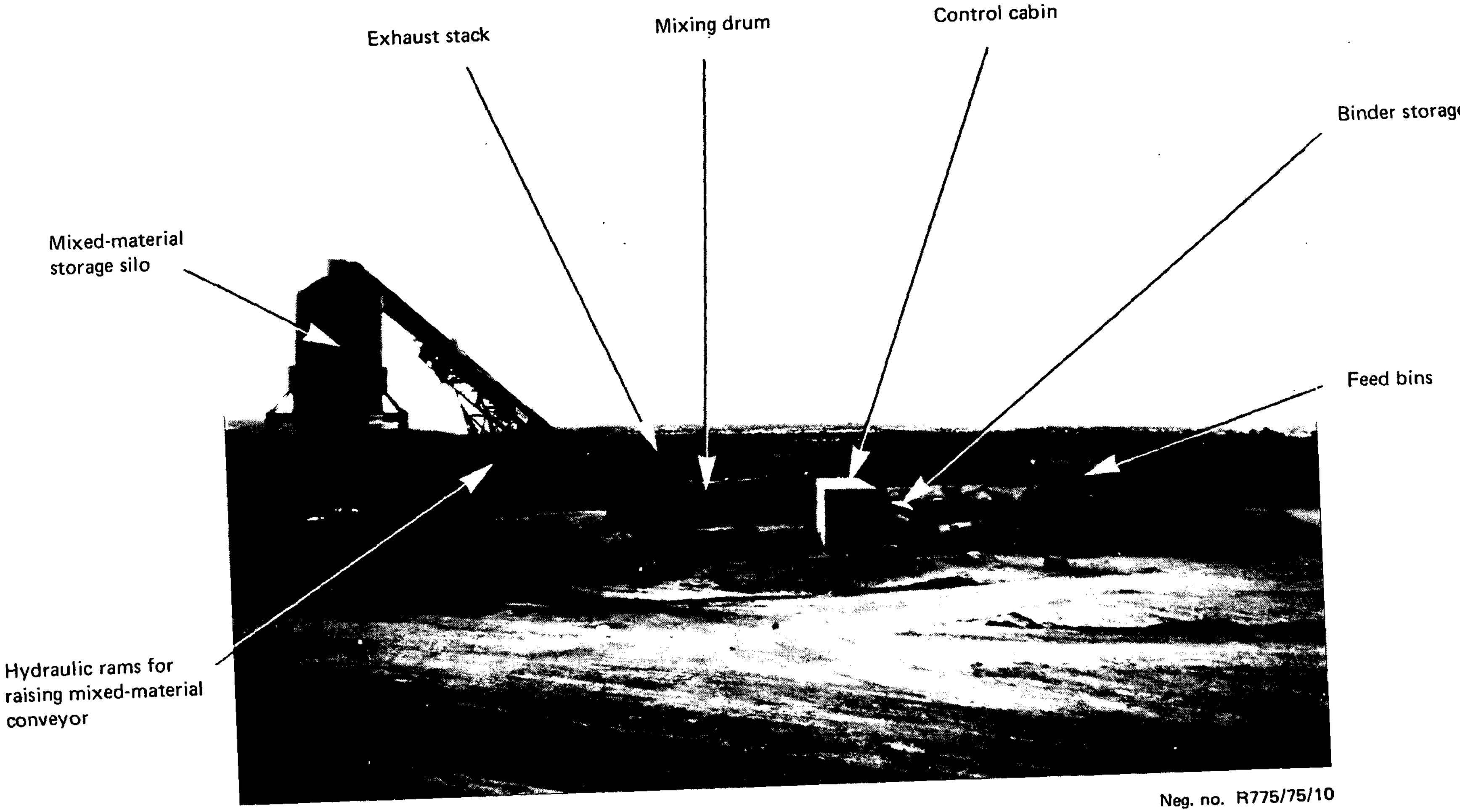


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PLATE 23
GENERAL VIEW OF BOEING MODEL 100 PLANT
CAMERON, ARIZONA

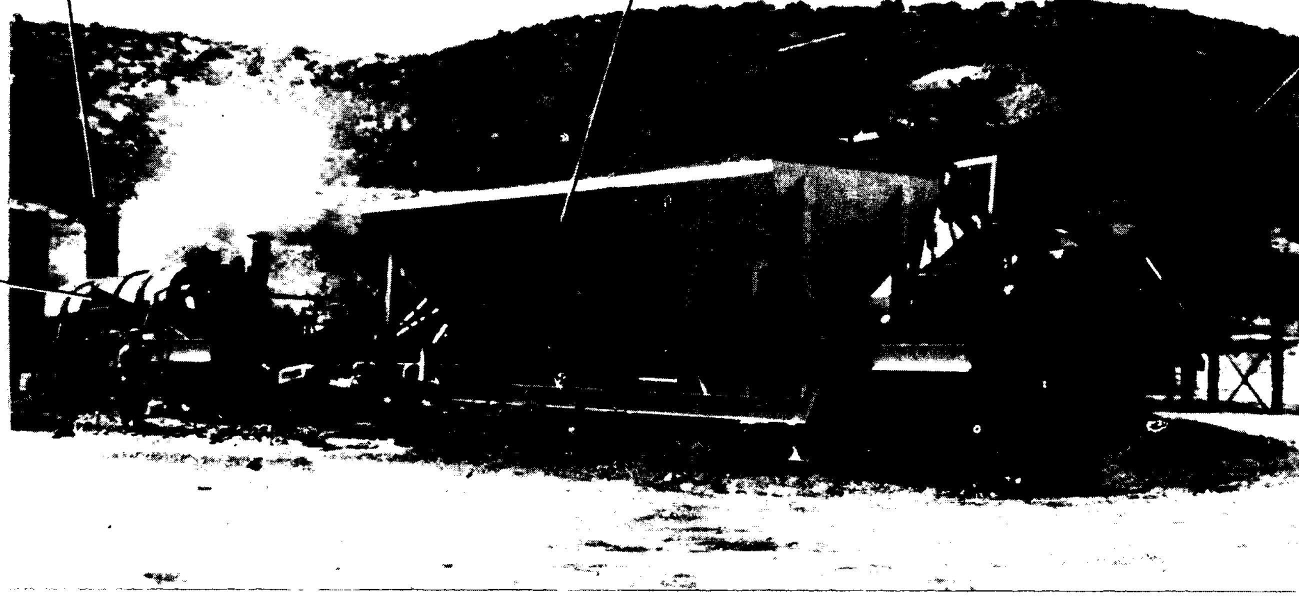

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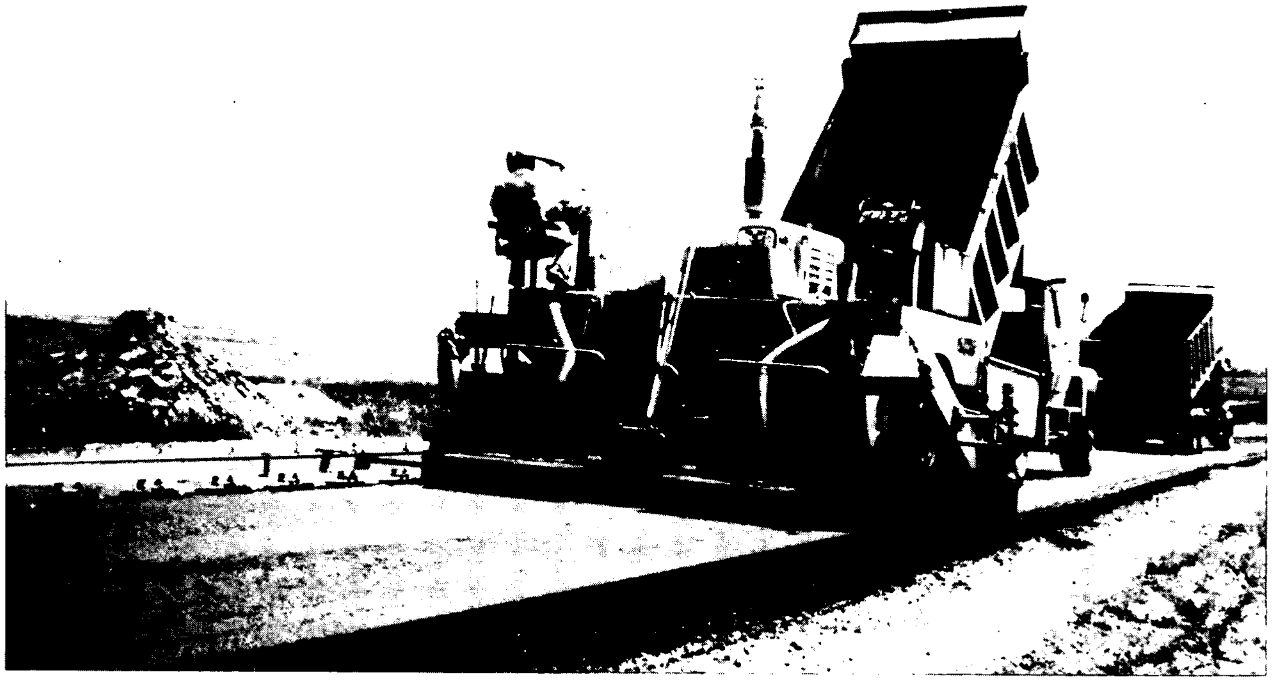
PLATE 24
GENERAL VIEW OF BOEING MODEL 80 PLANT
PRESCOTT, ARIZONA



Neg. no. R720/75/31

PLATE 25
LAYING OPERATIONS
RICHARDTON–MOTT, NORTH DAKOTA

Neg. no. R719/75/10

PLATE 26
EAGLE CREEK–ESTACADA HIGHWAY
OREGON

Neg. no. R719/75/16

PLATE 27
INTERSTATE HIGHWAY I 40
WILLIAMS, ARIZONA

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ABSTRACT

Bituminous drum-mixing plants in the USA: G D GOODSALL and B W FERNE: Department of the Environment, TRRL Laboratory Report 691: Crowthorne, 1976 (Transport and Road Research Laboratory). In recent years the United States of America has seen a rapid increase in the use of the drum-mixing process for the production of bituminous materials. The process uses a simplified plant in which mixing takes place in a drum similar to the continuous dryer of a conventional asphalt plant.

This Report describes the findings from a study visit to the United States, in June 1974, by a small group representing the Department of the Environment's Transport and Road Research Laboratory and Engineering Intelligence Division, and a member of the staff of the Amey Roadstone Corporation Limited representing the Asphalt and Coated Macadam Association.

The Report indicates that:

(i) the mixtures produced were well coated and handled in a normal way during paving operations

(ii) the gradings of the mixed materials were uniform but the test results for binder content indicated some variability

(iii) the recovered binder showed less hardening than obtained when mixtures have been conventionally mixed

(iv) the temperatures of the mixed materials were very uniform under the favourable operating conditions

(v) mixing and laying temperatures were similar to those used in the UK

(vi) the effect of the presence of any substantial quantity of residual water on the behaviour of mixtures during paving and rolling, and on the long-term performance of the laid material, has not been established

(vii) there was no evidence to suggest that the service life of the materials produced would be unsatisfactory

(viii) the exhaust emissions could be restricted to very low levels

(ix) the capital and production costs were lower than for conventional plants

(x) the general requirements of the State specifications for coated materials were applied; slightly lower materials temperatures and higher residual water contents were permitted for drum-mixed materials

(xi) a Provisional Specification covering bitumen macadams, with penetration-grade bitumens, and rolled asphalt base and basecourse mixtures could be issued

(xii) further evidence was required of the suitability of the process for the production of wearing course rolled asphalt with bitumen and pitch/bitumen binders, tarmacadams and materials containing cut-back bitumens.