HIGH PRODUCTIVITY CONTINUOUS CONCRETE MIXING SYSTEM

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Abstract: Newly developed continuous M-Y mixer has number of mixing units connected in series. When using it in the horizontal way, it fully complies the 2^n mixing theory of kneading and lapping mechanism. When using it in the vertical way, mixing work can be done under gravity force only, with the new modified mechanism of inter-particle collision and impact. The vertical set-up of M-Y mixer is renamed as Energy Saving Gravity (ESG) mixer to represent its mixing characteristic under gravity force only. A newly developed High Productivity Continuous Mixing System (new mixing system) is composed of ESG mixer, continuous conveying systems and real time monitoring system. This paper describes about this new mixing system and its practicability for concrete production work in dam project.

Keywords: 2^n mixing theory, kneading and lapping, M-Y mixer, inter-particle collision and impact, ESG mixer, new mixing system, real time monitoring system.

1. DEVELOPMENT OF NEW 2^n MIXING THEORY AND ITS VERIFICATION

The new 2^n mixing theory is mainly based on the kneading and lapping mechanism, similar to the traditional mixing method of Japanese noodles, *udon*. In *n* numbers of kneading and lapping process, 2^n layers of material are formed resulting in uniform distribution of each constituent [3]. With the development of one proto-type experimental mixer, this new mixing theory was verified as similar to that of the conventional one for the quality of mixed concrete materials both in their fresh and hardened state. Its merit was also marked out for mixing those viscous, light and lean materials, which were noticed difficult to mix in the conventional mixers [4].

2. DEVELOPMENT OF M-Y MIXER AND ITS MIXING EFFICIENCY

A continuous mixer, M-Y mixer (previously named as MY-BOX), was developed for the practicability of 2^n mixing theory [5]. The application of 2^n mixing theory in horizontal set-up of M-Y mixer is shown in figure 1. As shown in the figure, one unit of M-Y mixer has two vertical inlets and two horizontal outlets. As from inlet to out let vertical dimension gradually decreases and the horizontal one increases with same proportion resulting in similar cross-section area through out. When material is sent with pressure, inner structure of M-Y mixer makes it to be kneaded while passing through each unit. As passing from inlet to outlet, material compresses vertically and stretches towards horizontal direction. In this way, material entering into two vertical inlets of first unit becomes horizontally two layers in its outlet. Similarly, Materials passing through second unit form four layers, and eight layers from third unit. In this way, materials form 2^n layers when passing through n^{th} unit fulfilling the basic principle of 2^n mixing theory. Continuous mixing was possible in the horizontal set-up of M-Y mixer with the process of kneading and lapping by charging the materials in the continuous way using external pressure. It showed the merit over conventional method for mixing viscous and lightweight materials [5]. But, it was failed to mix materials of large size particles.

An attempt was made to modify the 2^n mixing theory to make the possible for mixing materials of large size particles in vertical set-up of M-Y mixer. The mechanism of inter-particle collision and impact was used in stead of kneading mechanism, which was further enhanced with the action of splitting and recombination of materials [2].

3. DEVELOPMENT OF ESG MIXER WITH MODIFIED MIXING MECHANISM

As shown in the figure 2, let A and B be two particles which are charged into M-Y mixer using external energy. When entering into M-Y mixer they have possibility of colliding each other before impacting into the inner sloped surface of M-Y mixer, case (a), or impacted into surface, case (b); and may collide after bouncing as well, case (c). As shown in the case (d), when two particles are dispersed after collision, they can be collided again with other dispersed particles. Therefore, number of chances for collision for one particle increases when increasing the total number of particles in materials. Such action of inter-particle collision and impact with surface makes the different types of materials in even distribution when passing through number of units of M-Y mixer.

The mixing characteristic of materials when falling through vertical set-up of M-Y mixer under gravity force is illustrated in figure 3. As shown in the figure, when materials are charged into M-Y mixer with external energy, they first impact on the inner slope surface of first unit of M-Y mixer (some part of materials may impact on the inner slope surface of attached hopper) while entering into two opening inlets. Such action makes whole materials to be split into 2 parts. Particles within materials have more chances to be collided with each other before impacting, after impacting and when falling through each openings as well. Moreover, they have also more chances to be impacted with the inner slope surface of M-Y mixer unit. When they exit from the outlet of first unit, they again combine making 2 layers, in general. However, due to inter-particle collisions and impact, particles are dispersed and distributed inside each layers. Since the materials from two outlets are combined with notable momentum, this combining action creates more chances for inter-particle collisions and impact with the surface. Just after the combining action, they are again split to two parts when entering to the inlet of second unit of M-Y mixer. Since the outlet of first unit and inlet of second unit are crossed with each other, half of the materials discharged from one outlet layers with that of another outlet. This action crates more possibilities for different particles to be mixed with each other resulting in more uniform distribution. Continuation on splitting and recombination of materials increases the chances for inter-particle collision and impact of particles with inner slope surface when passing through number of

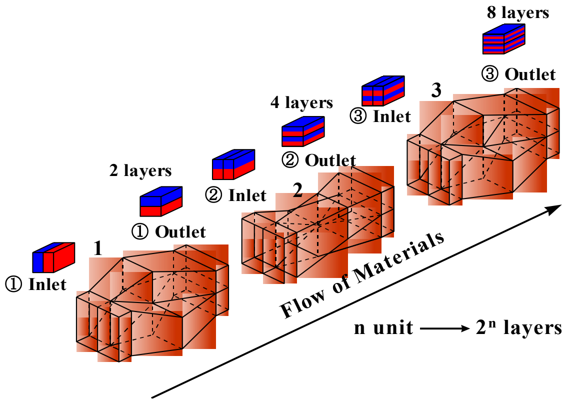

Figure 1. Mixing principle in horizontal set-up of M-Y mixer [5]

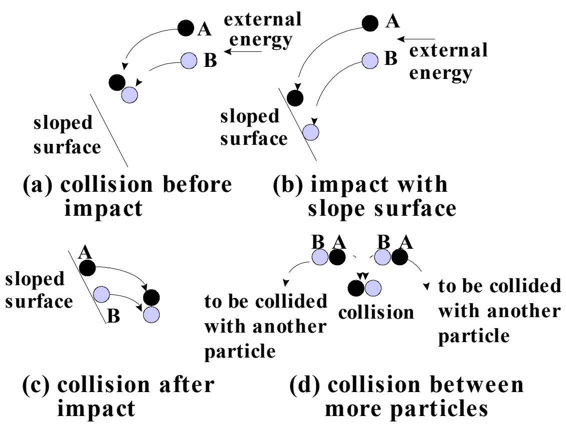

Figure 2. Basic Mechanism of inter-particle collision and impact [2]

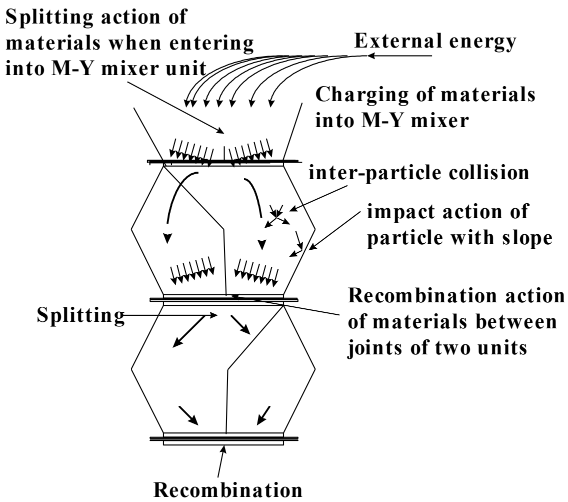

Figure 3. Expansion of basic mechanism in vertical set-up of M-Y mixer [2]

M-Y mixer units.

With the consideration of the above mechanism, it can be claimed that the mixing work in the vertical M-Y mixer is not kneading, it is certainly due to mechanism of inter-particle collision and impact, which is more enhanced due to the action of the splitting and recombination of particles when passing through number of M-Y mixer units. However, it is obviously true that 2^n theory still exists forming the 2^n layers of material when passing through n units of M-Y mixer since every materials have *n* chances of splitting and recombination. With this modified 2^n theory, mixing should be possible only with the gravity effect when materials falling freely inside M-Y mixer units, where any external energy is not required for mixing process. In general term, it can be said that the mixing criteria inside vertical M-Y mixer correlates with the mixing of sand by two persons using shovels to make the uniform distribution of surface moisture thoroughly.

In order to verify this assumption, mixing of two different colored grains was carried out [2]. For this experiment, 5 units of model M-Y mixer, opening size of 20mm by 20mm and slope of 63^o, were connected in vertical set-up. Two small vertical boxes were connected in the top of M-Y mixer to put the two different colored grains for feeding into two inlets. Small box was connected to the exit of bottom M-Y mixer unit to collect the mixed grain. The cover in between the upper boxes and first M-Y mixer unit was opened to feed grains into M-Y mixer for mixing. The falling condition of grains was carefully checked visually through each unit of M-Y mixer. With repeating this experiment, grains were collected in each unit, i.e. from first to fifth, to check the distribution condition of grains.

Figure 4 shows the condition of two different colored grains before feeding, while falling through each M-Y mixer unit under gravity and the mixing condition of grains in the first and fifth unit. It was observed from the experiment that materials in upper units distribute in the macro way. Then in the following units, the more distribution takes place within this macro mix and uniformity of the distribution increases in the lower units, like in 4th and 5th unit. As it can be checked from the figure that grains in the fifth unit are evenly distributed. The collected grains from the fifth unit of M-Y mixer were divided into 4 portions. Those were counted to find out the distribution variation of each colored grains in each portions. The variation coefficient of distribution was only 0.4% representing very uniform distribution.

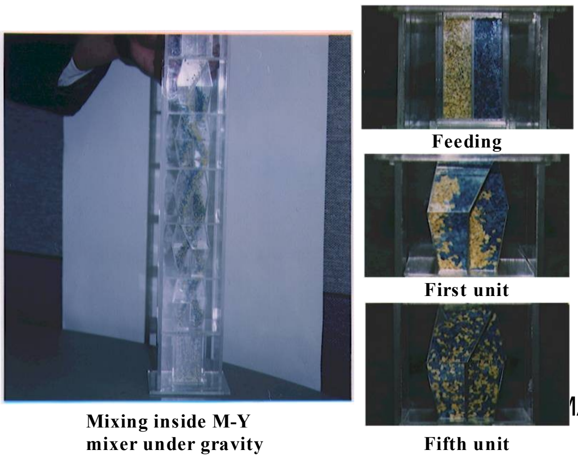

Figure 4. Preliminary mixing experiment in vertical set-up of M-Y mixer[2]

From this very preliminary mixing experiment, it was realized that mixing of larger particle size materials could be possible with the modified theory. Thus in case of vertical set-up of M-Y mixer, the mechanism of kneading was replaced by the mechanism of inter-particle collision and impact; which is more enhanced by the action of splitting and recombination while falling through its each unit.

In order to represent such new mixing mechanism with out use of any external energy, the vertical set-up of M-Y mixer was proposed to term as Energy Saving Gravity mixer (ESG mixer) [2]. With development of this ESG mixer, the original kneading and lapping mechanism was converted again into mixing mechanism, which is still strongly alive in all type of conventional mixers.

The modified theory resulted in the reduction of the external energy to be required for mixing, since materials could be mixed when falling inside M-Y mixer under gravity force only. Different types of concrete materials, including RCD, dam concrete etc., were made possible to be mixed resulting in similar properties with that of conventional method. Moreover, ESG mixer has gained its category as High Performance Mixer (HPM) class over all from its comprehensive assessment by carrying out all tests compiled with the highest requirement specified by RILEM TC 150 [1].

With development of model continuous mixing system, it was verified that ESG mixer has a significant high efficiency for mixing different types of concrete continuously giving similar quality to that from conventional mixers [6], [7].

4. HIGH PRODUCTIVITY CONTINUOUS MIXING SYSTEM

Now in big construction industries, like dam project, main concern is first how to rationalize the overall construction work in respect of cost and duration; and second, how to control the environment protection. In this respect, the development of high productivity continuous concrete mixing system (new mixing system), using ESG mixer, mainly falls on two following proposes:

1. To mix the concrete continuously which results in the production of high volume of concrete in short time; symbolizing the rationalization for the production of concrete.
2. To control the environmental burden with reduction of electric consumption.

4.1 Features of New Mixing System

With the main aim of the aforementioned two points, new mixing system was built to give the following features:

1. Since the mixing work in this system can be carried out continuously, i.e. the charging of concrete constituents and the discharging of concrete consequently, there is no time loss during mixing work, which happens in batching plants.
2. In comparison with the conventional batching plants, since this new plant does not contain any big containers like materials bin or weighing equipment, the plant itself is more simplified and compacted.
3. Since mixing work in ESG mixer of this system is carried out completely under gravity, no any external energy is required for mixing.
4. The quality control for feeding of each constituent can be carried with real time monitoring system.

Moreover, since conveyor-belts can be set-up, from out side of plant, to supply different materials into the plant, the plant can be set-up in geographically difficult situation. With use of high efficiency supplying systems, mixing rate can be greatly increased resulting in great reduction of concrete production cost.

The capacity of this system was based mainly on the construction speed and the concrete placing rate in the dam. The construction period of this dam was 15 months. For this propose, the 40m^3/hr. capacity conventional mixing plant, with two forced type mixer of 1.5m^3 capacity, was built to produce mortar as well as to produce the concrete itself in order to carry out the comparison work with new mixing system in the actual field. For this, the mixing rate of this system was maintained only 100m^3/hr.

4.2 Functions of New Mixing System

The overall image of this new mixing system is shown in figure 5. It has the following functions:

1. The main conveyor-belt, 750mm width, set-up in this system has the capacity of 277.8 ton/m^3, equivalent to 170m^3/hr. However, only 70m^3/hr. capacity of this belt was used with the consideration of whole construction situation.
2. In order to supply the coarse aggregates from bin precisely to control its variation within 3%, vibration feeder and constant feed-ware are adjusted in two stages. In this set-up supply rate can be adjusted by controlling the rpm of motor drive with the confirmation of supply rate and its variation displayed in constant feed-ware.
3. Unit weight of mortar mixed in batching plant is fully adjusted with the consideration of moisture content of both of the coarse and fine aggregates.
4. The confirmation of the total weight of different grade of coarse aggregates adjusts the supply rate of mortar from pump.
5. The total weight of concrete materials, i.e. mix of coarse aggregates and mortar, can be weighed and recorded continuously, before feeding to ESG mixer for mixing.
6. When mixing concrete continuously in this system, the mix proportion of concrete can be changed consequently in zero intervals. Unlike in batching plant, the mixing work need not to be stopped for this change; but the consideration is made that there would be no problem if a little part of rich mix is mixed to poor mix, while changing from rich mix to poor one and vice versa.

4.3 Mixing and Placing Work of Concrete

Although this system is completely high productivity continuous mixing plant, the batch type method was applied with the consideration of concrete placing work, using the buckets of 3m^3 and 4.5m^3 capacity. In order to manage this job, the minimum quantity of concrete was considered as unit and controlled by computer. The mixing and placing schedule of concrete was carried out with the management of these units. In the screen of the computer, 20 units were set for coarse aggregates and

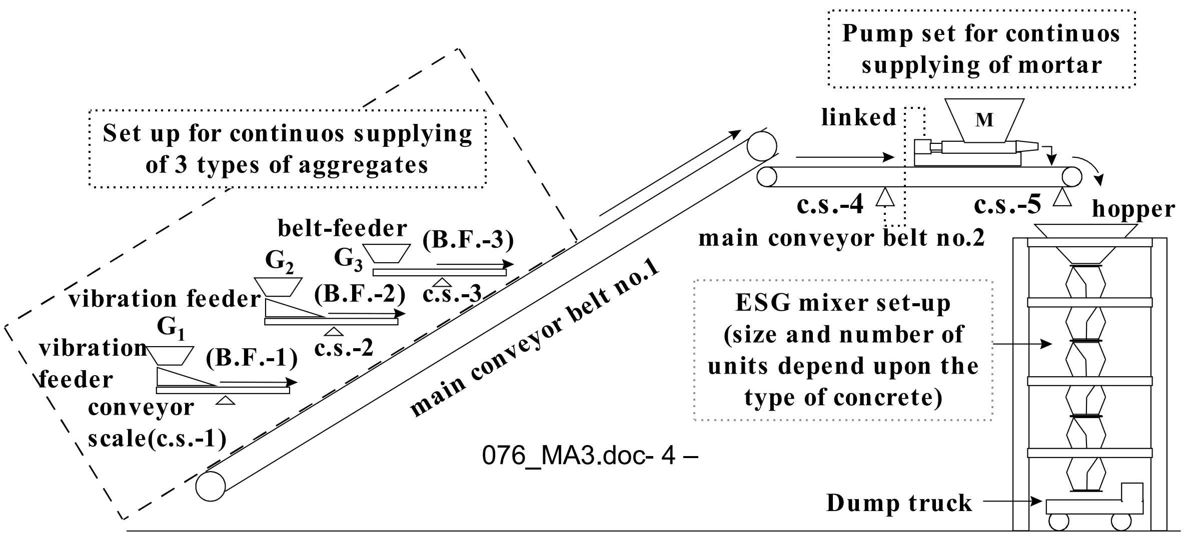

Figure 5 General view of High Productivity Continuous Concrete Mixing System

mortar of different types of concrete and schedule, completion of mixing, under mixing and not batching units were separately shown in the screen.

The supply condition of each constituents of concrete was shown and managed by real time monitoring system in real time when mixing. The upper and lower boundary for the supply rate of different types of coarse aggregates and mortar were fixed to confirm that each controlled rate was in between the boundary line.

When mixing mortar, checking the moisture content of fine aggregates as well as of coarse ones controlled its unit content. Its quality was controlled with the relationship between the slump flow and decrease of unit water content. During the mixing work of concrete, the whole system was managed to stop within 10 seconds in the condition supply rate of any constituents was found outside of boundary line.

The mixed concrete from ESG mixer was first collected in $6m^3$ hopper and then transported to the

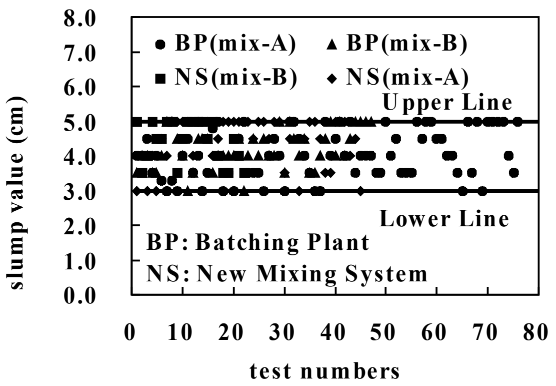

Figure 6 Slump test results of concrete

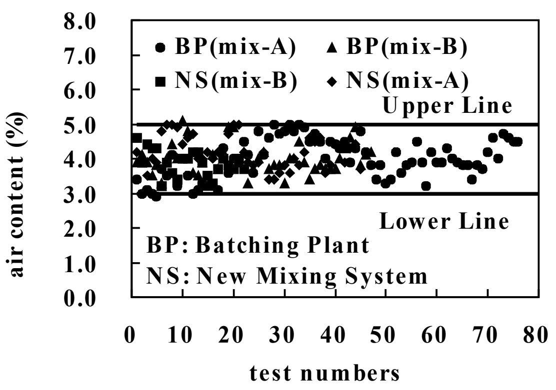

Figure 7 Air content test of concrete

site using dump truck. The concrete placing work was carried out using bucket; the handling of which was done automatically using remote control system.

4.4 Comparison of New Mixing System with Batching Plant for Concrete Quality

Table 1 gives the mix proportion of two types of concrete used for the construction of this dam project.

Table 1 Mix proportion of concrete

Mix	G_{max} (mm)	W/C (%)	s/a (%)	Slump (cm)	Air (%)	W (kg/m^3)
A		48.7				115
B	80	64.2	28	3~5	2~4	113

The quality of mixed concrete, both in batching plant and new mixing system, was checked with slump, air content, compressive strength and other required tests in regular interval during concrete production work.

Figure 6 and 7 give the over all slump and air

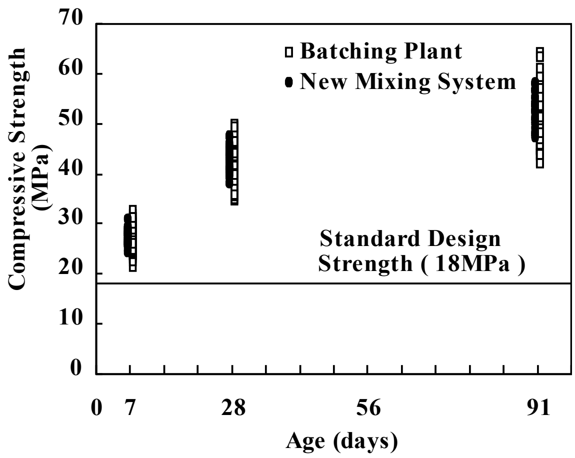

Figure 8 Compressive strength of mix A

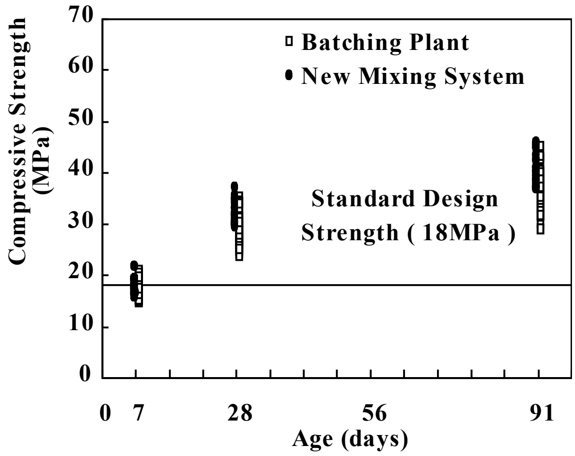

Figure 9. Compressive strength of Mix B

content test results of concrete respectively. It should be noted that the upper line and lower line for the air content value in the figure 7 is different with that range given in the table 1. It was because aggregates of 80mm size were avoided by screening the concrete through 40mm size mesh for the air content test, for which the calculated range was designed as 2.6~5.1.

As it can be checked from both figures that values in all tests of concrete, both mixed in new mixing system and batching plant, were within the required range.

Figure 8 and 9 give the compressive strength test results of mix A and mix B of concrete respectively. Its result is summarized in table 2 with number of total tests (data nos.), average values (avg.) and variation coefficient (v.c.) of both type of concrete mixed in new mixing system and batching plant. Test results show that the concrete mixed in new mixing system has little more precise in its compressive strength than that in batching plant.

Table 2. Summary of compressive strength test results

Mix	Age (da-ys)	Batching Plant			New Mixing System		
		data nos.	avg. (MPa)	v.c. (%)	data nos.	avg. (MPa)	v.c. (%)
A	7	78	26.8	8.6	44	27.4	4.9
	28		41.4	9.0		43.1	5.1
	91		51.8	10.3		54.0	5.6
B	7	44	17.1	9.1	23	18.1	7.5
	28		28.9	10.3		32.4	6.6
	91		36.1	10.6		40.3	7.0

5. CONCLUSIONS

The application of the mechanism of inter-particle collision and impact has made possible to mix the materials of large particle size like different types of concrete in vertical set of M-Y mixer. Vertical set-up of M-Y mixer was proposed to rename as Energy Saving Gravity mixer (ESG mixer) to represent its mixing characteristics under only gravity. The high productivity continuous mixing system, using ESG mixer and large capacity conveying system, has capability of producing large quantity of concrete with its precise quality. The use of this new mixing system in big construction industries not only rationalizes the concrete production work, but also helps to protect the environmental condition by decreasing electric consumption in large scale.

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