Progress and Key Technical Control Points of Side Slip-form Construction Technology

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Abstract. Slip-form pavement of road surface construction is an efficient mechanical construction method, compared to the traditional construction method of erection of template for cast in situ or backcourt prefabrication while hoisting in the front court, slip-form construction technology dispenses with the prefabrication site and a lot of prefabrication dies, meanwhile, it reduces the process of handling and lifting, and can improve the flatness of the structure to obtain beautiful line type and unified color. Moreover, it can achieve “low-carbon” construction by reducing the energy consumption. In this paper, introduction was given for key technology of the construction technology and the current foreign development situation, to provide a reference for engineering technicians.

1. Introduction
Highway concrete construction on the surface specifically refers to curb, concrete anti-collision wall and various drainage (intercepting) facilities. There are three construction methods for these concrete constructions: erection of template for cast in situ, backcourt prefabrication while hoisting in the front court as well as slip-form paving [1]. Concrete slip-form paving construction method indicates one-off paving of anti-collision wall and other constructions on the road surface without template laying in advance with the help of professional slip-form paving machinery, its advantages include: (1) slip-form construction can greatly improve construction efficiency, compared to cast in situ, there is no need for erection of template in advance, relevant personnel only need to place isolation panel between a certain length; (2) slip-form construction is of goof appearance and integrity, which is conducive to the overall color decoration of the construction. Compared to the traditional technology of prefabrication before installation, slip-form construction technology dispenses with prefabrication site and a lot of prefabrication dies, meanwhile, it reduces the process of handling and lifting, while improving the flatness to obtain basic characters of beautiful line type and unified color, it can achieve “low-carbon” construction by reducing the energy consumption. Besides, construction technology establishment of cast-in-situ fixed mold also requires lots of molds, and it is slow in construction speed. Therefore, studying the new technology on slip-form paving of road surface construction will be definitely conducive to improving mechanical quick construction technical level of construction concrete and the project quality; enhancing labor productivity and reducing construction cost; boosting the appearance of the construction and greatly extending its service life. Along with the quick and stable development of high-grade highways in China, it is an irresistible trend to comprehensively promote mechanical construction, and it is of great significance to improve construction quality and accelerate the construction progress. The technology can enhance construction stability, and ensure concrete quality of the construction, which is of great significance for improving safe operation of the expressway.
2. Progress of Side Slip-Form Construction Technology at Home and Abroad

2.1. Overview of Foreign Development

The earliest curb dated from America in 1950s, in order to change the traditional inefficient manual operation method in the highway curb construction, the concrete building contractors developed the early curb paver [2]. Such machinery is under extrusion-type, which uses the screw device in the mold to extrude the asphalt concrete materials or dry cement concrete materials, to form the construction with the same shape of the mold. Since this machinery has special requirements for cement concrete materials, it is not convenient to use. Up to later 1960s, via the test by some contractors, a slip-form curb paver appeared. Such curb paver could pave curb, side ditch, sidewalk and other various concrete road surfaces by changing the molds in different cross-section shapes. Meanwhile, it greatly enhanced labor productivity, the project quality was higher than that by manual operation, and the cost was much lower [3]. Invented by John Leone, the curb slip-form machine obtaining US patent in 1991 has become a relatively mature curb slip-form machinery, see Figure 1.

![Figure 1. Curb Slip-form Machine Invented by John Leone](image)

Along with increasing expanding of highway construction scale, the use of side slip-form paver has become commoner. In foreign countries, it has become one of the main equipment for road construction. There are two types of 5700 multi-functional slip-form cement concrete paver produced by Powecurber company in America, namely, standard three-track type and special four-track type, see Figure 2. They can achieve both straddle and lateral paving, and slip-form paving of the integral isolation belt in various shapes, widths or variable cross-sections, as well as the ditches, curbs, railings and cement concrete pavements in different shapes.
Gomaco in America is good at cement concrete paving technology, and it has nearly 40 years of research and practice experience in the professional field of slip-form paving. The GT series products produced are under multi-purpose design, for example, GT-3200 slip-form paver can not only pave curbs and side ditches, it can also change different molds to pave road surface, anti-collision wall or bridge parapet wall, channel etc., one unit with multiple purposes, which is flexible and convenient, see Figure 3. New GT-3400 slip-form paver can conduct two-way paving at left and right for curb, side ditch, small-space curve, anti-collision wall, bridge railings, side shortcut, recreational path and flat road surface, and the paving width can be up to 1.8m, the equipment can either be controlled by guide line or equipped with three-dimensional wireless control system. Besides, Commander III is the most popular slip-form paver among Gomaco product series, since coming out, its global sales volume has exceeded 2,400 sets. Meanwhile, its multi-purpose design is of great flexibility, which enables it to be competent for whether curb, side ditch, sidewalk with curb, anti-collision wall, bridge safety barrier, irrigation or drainage ditch or 6m-wide road, airport runway, non-ballast track of high-speed railway, monolithic concrete bed, subway, light rail, railway or highway tunnel etc.

ARROW Machinery in Australia is also a manufacturer specializing in design and manufacturing of curb and anti-collision wall paver, with the production history of over 30 years, currently its products are distributed in more than 40 countries. The curb paver produced by ARROW Machinery in Australia has received universal recognition of users for its performance and quality, and it enjoys a very high reputation. Arrow 770 curb paver can tamp and extrude the curbs of over 1,000m every day, meanwhile, it can make sharp turn with the semi-diameter of only 4.6m, and get close to the obstacle with the closest distance of 1m. The compression effect of the machine is obtained via ramming system, wherein the concrete is tamped and extruded into the mold connecting to the host by the ramming system. The machine itself does not have power, and wheel forwarding comes from counterforce of ramming motion.

In addition, ROBOT slip-form curb paver of CURBMATER in America is self-propelled, the slip-form control over vibration and tamping can be applicable to high slump concrete, and it can pave curb, curb ditch, sidewalk, safe grid etc. There are two paving methods, including straddle and lateral paving. The foreign slip-form paver has strict requirement for concrete consistency, and there is high difficulty in construction technology. Compared to traditional curb prefabrication technology, its construction cost is too high, therefore, it is not widely promoted in China.

2.2. Overview of Domestic Development
In recent 20 years, some institutions in China has developed several relatively simple curb automatic molding machines, but compared to the actual construction requirements and foreign curb pavers, they still lag far behind whether in product performance, quality, productivity or scope of application and construction conditions etc. In late 1980s, Beijing First Municipal Engineering Co., Ltd. developed curb automatic molding machine and conducted product test evaluation. In September 1989, Xi’an
Highway Research Institute completed trial-manufacturing of curb automatic molding machine, and carried out the test in the construction site of the first-class highway from Xi’an to Sanyuan. After that, in November 1989, it was officially put into use in Xi’an-Sanyuan Highway, and good results were received. In addition, as for LCI slip-form machine developed by Hebei Transportation Research Institute together with Highway Bureau of Hebei Province, its prototype was produced by Lulong Road Construction Machinery Factory in Qinhuangdao in early 1992, and the pilot production was implemented in the expressway construction site of Beijing-Shijiazhuang section of G107, as a result, good results were received, see Figure 4. The YC15 slip-form machine developed by Institute of Construction Mechanization of China Academy of Building Research and Dongguang No.1 Machinery Factory on the basis of absorbing Japanese type passed the appraisal in Hebei Province in December 1992. Though these products are different in forms and performances, they are basically the same in operating principle, structural form, technical features and construction technology.

Figure 4. LCT Paver

The BL790 full-automatic curb paver produced by Beijing Sona Measurement and Control Technology Co., Ltd. is under hammering construction, see Figure 5. Under this method, the extruded curb is of high compaction, hard texture, and under the circumstance with the same design, the formed curb intensity is about 20% higher than that with vibration. After molding, the curb is of high shock strength and stability.

Figure 5. Sona BL790 Paver

Figure 6. Paver Produced by Siming

In 2004, Jiangsu Siming Engineering Machinery Co., Ltd. developed multi-functional curb slip-form machine independently by combining the advantages of imported slip-form machine, see Figure 6. The machine can not only pave the high slump concrete, but the hard concrete. Meanwhile, it has a low requirement for mixture, which solves the problem of high requirements of imported slip-form
machine for concrete slump. Therefore, it is a slip-form machine suitable for China’s national conditions.

3. Key Technology of Efficient Side Slip-Form Construction

3.1. Vibration and Compacting of Concrete
During slip-form paving of concrete anti-collision wall, the mixture consistency shall be able to achieve vibration liquefaction, and reach the compacting status within the propulsion duration. The EU anti-collision wall slip-form paver is equipped with 3 super high frequency vibrating rods, with 1 at both sides of the lower part and 1 at the upper part. During the propulsion of slip-form paver, the newly mixed concrete must have been vibrated and compacted [4].

3.2. Speed Control of Slip-Form Paving
The paving speed for anti-collision wall shall be controlled between 0.75m/min-1.5m/min according to speed of material supply, vibration and compacting, paving effect etc. Under normal circumstances, during anti-collision wall paving, the propulsion speed of slip-form paver unit (including continuous unloading) shall be about 1m/min. Besides, the slip-form paving speed of anti-collision wall shall make sure the appearance and elevation of anti-collision wall meet the requirements.

3.3. Control of Elevation and Flatness
During paving, the top slump of anti-collision wall shall not be greater than 4mm±1mm when the vibrated and compacted concrete leaves the slip-form mold, and it shall remain constant in the paving process without reapplying thin-layer mortar for local heightening after slumping. It should be known that if reapplying mortar after anti-collision wall paving, it is difficult to paste mortar firmly under the effect of thermal and air shrinkage, and it will automatically fall within half a year under the effect of year temperature difference. The anti-collision wall top face shall be placed with a 5m ruler for flatness detection at any time, and the flatness good rate at the top face must reach the standard. The requirements of EU on flatness of anti-collision wall is that it shall not be greater than 3mm via 5m ruler, which is higher and stricter that that in China’s guidelines [5] [6].

3.4. Concrete Bottom Setting
At one side of the road surface, the slip-form paver shall march in the middle surface course of the asphalt concrete, after hardening of anti-collision wall, 40-50mm asphalt concrete surface layer shall be paved, namely, one side of road surface of concrete anti-collision wall shall be buried 50mm in the asphalt road surface.

3.5. Slight Hand Retouching on the Concrete Surface
The concrete anti-collision wall after depanning has been very regular in the appearance, and there are only few pores and individual stone marks dragged by slip form, which requires slight hand retouching. The optimal effect is that the anti-collision wall under slip-form paving is almost free of defects, and no need for any surface retouching [7] [8].

3.6. Geometric Dimensioning Calibration during Concrete Paving
During marching of slip-form paving for concrete anti-collision wall, the paver driver shall constantly use detection tools to measure and calibrate geometric dimension, location and variation of concrete construction, and control the paving location deviation of anti-collision wall within 10mm.

4. Conclusion
Side slip-form construction technology is an efficient mechanical construction method, compared to the traditional construction method of erection of template for cast in situs or backcourt prefabrication while hoisting in the front court, it is featured by high construction speed, good concrete compactness and favorable concrete linear appearance quality etc.
Construction effect of side slip-form concrete should be judged and the technical points shall be controlled from concrete vibration, paving speed, flatness control and other aspects.

5. References
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