BALI'S SUBAK WATER MANAGEMENT SYSTEMS IN THE PAST, PRESENT AND FUTURE

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ABSTRACT

The existence of Subak is still needed for agriculture development especially in the rice field in Bali. Subak approach might be good to be introduced to other places nationally or internationally. The system might be required to be corrected, so as to make more effectively, efficiently and scientifically and could be adapted to other place outside Bali. The Subak in Bali famously known and traditionally exist and impressive and open to the achievements in a modern situation. Due to lack of the available of finance, some infrastructures of the Subak need to be replacing with a better condition, for example the conditions of water control structure weirs which were still made of simple wood construction.

Some improvements should be done to improve the quality of the Subak scientifically, especially related to the hydraulic performance of the system. Irrigation water division should not be just evenly distributed, but also based on crop water requirement and their development stages. In this case, analysis on crop water requirement at the field level by using lisymeter needs to be carried out. Then crop water requirement was calculated by using CROPWAT model. Based on the crop water requirement and the availability of water, water distribution by using SUBAK principle and approach can be expected to be more accurate and realistic. In this research, next to the principle and approach of SUBAK, hydraulic mathematical modelling was also used in order to evaluate the operation of the system and their hydraulic performance.

In this research, several alternative crops, rotation system included cropping pattern have been checked with the objective to achieve a better farming, more sustainable farm and increase the farmer's income.

Finally, recommendation is also presented to apply the approach and principle of SUBAK with some limitations for the water management systems in tidal lowlands where the systems are influenced by the tidal fluctuation.

Keywords: *Subak approach, water distribution, crop water requirement, drainage, mathematical modelling, hydraulic control strictures*

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INTRODUCTION

For centuries, Balinese farmers have been engaged in cooperative agricultural practices (Stephen Lansing and Miller, 2004). Subak in Bali has the function to distribute water evenly and appropriately among their members. This cooperative organization then famous called Subak. Actually Subak consisted of three aspects:

- Farming/technical aspect: this aspect concern with the field area, crops and the techniques of crops production. In extent of Cropping System and Cropping Pattern. Then other activities related to farming activities including irrigation water managements. This last activity manages in a good organization famous they called Subak. And some times they as the definition of the Subak. For excess water one farmer could not flow out the water to the neighbour's land, but should has special ditch (drainage ditch) and flow out the water to the lower public ditch. The area or territorially a relatively small Subak usually in a certain area with the same irrigation water source. Based on this location of the Subak, the Subak members might be come from several villages surround the Subak sites. In a wide area of Subak, with a big source of irrigating water, the sites might be divided into several Subak. The division of the sites was made wisely based on the sub-division of the irrigation water. In a relatively small Subak division like this might be done, but they called Tempek (consisted of some farmers related to the block area). This is done to make better organized in doing and communicate the every things related to the Subak. The union of several Subaks in a wide area we called Subak Gede (gede means big). The members of the Subak average 92 small individual farms (Ramaswati et al., 2007);
- Social aspect: concern with the rice farmer's organization with all activities that they have to do for the Subak. This social organization consisted of the member (the rice farmers) and some of them to be the board of the organization. The members of the Subak may be the owner of the rice field or the representative. The persons in the board, they elect democratically in a Subak meeting. The board of a Subak consist of: The Pekaseh (as the head of the Subak) and then assisted by some Kelian (as the head of the sub-Subak) and some juru arah for sub-Subak (person for doing communication to the members related to the activity should be done). They make rules (called awig-awig) usually locally for the Subak. The present of Subak make the work of the social/extension services from the government through Department of Agriculture to be easier.
- Religious aspect: related to the Hindu in Bali, they believe that the Goddess of the rice they called Dewi Sri. And the God to give liveliness, happiness they called Dewa Wisnu. These God and Goddess are also concern with the successfully of the crops production in the rice field. For this, the Subak make special offering to the God and Goddess. In a Subak usually they have temples, the biggest one they called Bedugul (the main temple) for the Subak, the smaller one they called Ulun Suwi, (this temple usually situated close to the first biggest weir of the Subak) and the smallest one usually close to the inlet of the irrigation water of the individual rice field (called sanggah uma/catu). All rituals for the Bedugul and Ulun Suwi conducted by the Subak, but for sanggah uma will be done by the individual farmer.

With these three aspects consistently exist make the Subak as a firm body since a long time ago and might be for ever. Subak actually a dynamic body and open to the achievements of modern agriculture. Up to day Subaks in Bali have a very important roles for the successful increasing the rice field production programs. The principles of Subaks in Bali in general are the same, but due to different costume, different conditions and some different problems, might be the Subaks still varies among the regions.

The member of the Subak association is those who own land needs water supply to grow crops. Depending on the capacity of water supply, the number of the member are varies from one association to another. The name of this association is " Sekaa Subak", which is cross border of traditional organization which is already exist such as Banjarese or Buginese or desaor even formal border set by modern government of Indonesia. Every Subak organization is an independence organization autonomous in their administration, in case land owner has 2 plots of land and each belong to different Subak organization, and then he/she must enters 2 memberships.

SUBAK IN THE PAST

In the period of 1960's and 1970's the population growth in Indonesia was high, so, especially in Jawa and Bali, the population to be more and more crowded. On the other hand, food crops (rice) in that time still using local varieties with a low potential yield, but with a nice taste. During that period some people starving some times happen.

With the successful of the green revolution, the Indonesian government introduced the high yielding varieties of the rice, through Department of Agriculture; the farmers adopted quickly those varieties due to high yielded rice varieties although the tastes were not as good as the local varieties. The quick adopted the new varieties by the farmers in Bali supported by the existing of the Subak. By this adoption of the new rice varieties, make the people could fulfil the requirement of rice as the major food of the people in Indonesia. By the time, the tastes of the new rice varieties continuously are corrected through the programs of plant breeding and today we have high yielding varieties with nice tastes.

In the past, Subak took part actively for the introduction of new findings in agriculture so as to increase the farming production and farmer's income. For examples for introducing new farming techniques, new varieties, fertilizers, and pesticides to the farmers, the Subak was actively took part. In communication, the presence of the Subak makes it better.

Soil tillage usually they do by using cattle (ox/en, cow/s or buffalo/s) in Balinese called metekap. Soil tillage consists of hoeing, ploughing, and harrowing. Hoeing they do where necessary, in the area where ploughing using cattle could be reached. Ploughing might be 1-2 times and harrowing might be 2-3 times. Ploughing and harrowing, they do intermittent and the last harrowing is the finishing for soil tillage, and the field ready to be planted. Beside that, cleaning the field from the weeds also they do just before the last harrowing. This preparation usually they do before the seedling ready to be transplanted from the seedling plot to the field.

SUBAK IN THE PRESENT

With the existence of the Subak the government and the people could doing their jobs, more quickly, effectively and efficiently. The two ways communication between the farmers and the government could be done smoothly without significant constraints. To day the Subak is still needed for increasing the development in agriculture especially in rice field farming. Through Subak the introduction of new rice varieties or demonstrate a new agricultural techniques or conducted a demonstration plot including training for the farmers could be done effectively.

With the successful of Subak in the rice field, recently system and terms of Subak also has been used in dry/upland farming, but they called Subak Abian (abian mean plantation in this case in dry/upland farming). The plantation in dry/upland farming in Bali such as coconut, coffee, cacao, clove tree, bananas or mix plantation. The principles of Subak Abian are the same with Subak for rice field. Subak Abian organized everything related to dry/upland farming, including for livestock. Subak Abian may has not temple like Bedugul or Ulun Suwi Temple, but for the individual farmer usually the same, in the rice field they called vary such as Sanggah/Catu Uma (uma=rice field in Balinese) and in dry/upland they called Tugu. Subak Abian also progressing a god impact for dry/upland farming. Recently there are 1,546 Subaks (rice field Subak) and 799 Subak Abian (dry/upland Subak) in Bali (Erviani, 2009).

The individual rice field farmer is not allowed to flow out water to the neighboring rice field, but should be flow out to a special ditch or to a public ditch below the field.

Soil tillage nowadays many of them use tractors, because more quickly and reduced man power for doing the job, but need to be paid with a certain price per a certain area. This also cause by the area for looking after the cattle in dry/upland area reduced, because the apply intensive farming in the area where in the past they looked after their cattle. For example in the past the area they grow only coconut, but today that area they planted cacao under the coconut trees. So, no more grass available for the cattle. Besides that by using tractor make doing the jobs in the farm to be easier.

SUBAK IN THE FUTURE

Subak system in Bali has been famous in the world and has been existed for hundreds of years, but in the future need to be improved to make it in better conditions. Better in organizations, rules and better understanding of the farmers on agriculture. This could be done through training for the farmers, conducted demonstration plots, take the farmers for trips for study comparisons to some other places with a good farming and other special ways for increasing the farmer's skill.

The source of water can be taken from a river or a main canal and the system is able to asses how to measure the gravitation level so as when the water flows reaching the agricultural field it is exactly as planned although some higher land might not get water. The related cropping calendar is almost neglected and the principle is based on the full supply conditions.

For water division in the future, need to be improved, not only just evenly and proportionally, but need scientifically calculated based on the plant water requirement and water loss related to water balance in a certain area. By these improvements, the water can be used effectively and efficiently for the rice field. At the presence, rice field in the upper stream might be using water excessively, whereas in middle stream and down stream not sufficient water could they used. In case of the available water for the Subak is excessive , by that ways the water could be allocated to the other Subak that is needed, or to the other purposes, as in the future water is as an important natural resources that required by many sectors.

By this improvements, Subak not just famous for the systems, but scientifically could be introduced to the world.

So far, the delivery system based on proportionality and under steady state conditions. This is a very good approach especially if a free over flow the structure can be guarantee. In case the downstream water level influences the flow conditions, then a better approach should be applied. For example if the Subak system will be applied in the lowland areas where they are influenced by the tides (downstream). In this case the width of the structure will be used as the ratio. But, in case the system is influenced by the tides (lowland areas), next to the proportionality, a flapgate should be introduced and this can also be applied in the Subak system.

MATHEMATICAL MODELLING APPLICATION

By using the traditional way of water distribution (the width of the structure opening is linearly proportional to the water distribution), it works perfectly when the availability of water is not a problem and the flow is free over flow. But when the system is influenced by the tides, this approach should be modified accordingly. In this case, the hydraulic performance of a Subak system can also be analysed by using a hydrodynamic mathematical model. The unsteady condition of the system even can be evaluated more reasonably. Based on the mathematical modelling result a set of simple operation rule can be derived.

So far, the distribution of water is done based on the proportionality principle only.

To be more efficient in water use and to distribution, crop water requirement can be calculated by using CROPWAT model for example and based on the result of CROPWAT, Subak water management system can be operated properly.

The values of decade or monthly reference crop evapotranspiration (ETo) are converted into daily values using four distribution models (the default is a polynomial curve fitting). The model calculates the crop water requirement using the equation:

$$ETc = ETo * Kc * Area \qquad (1)$$

Where: ETo; reference evapotranspiration (mm/day);

Kc: crop factor (-).

This means that the peak crop water requirement in mm/day can be less than the peak ETo value when less than 100% of the area is planted in the cropping pattern. The average values of crop coefficient for each time step are estimates by linear interpolation between the Kc values for each crop development stage. The “crop Kc” values are calculated as Kc*crop area. This means that if the crops cover only 50% of the area, the “crop Kc” values will be half of the Kc values in the crop coefficient data file.

For crop water requirements and scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values. CROPWAT for Windows does this in two steps. First the rainfall from month to month is smoothed into a continuous curve. Based on crop water requirement and availability of rainfall, additional irrigation or water supply can be determined. The irrigation scheduling will be done related to the status of the soil moisture every time new water enters the soil, either by rainfall or a calculated irrigation application.

The next point is how to supply the additional water from the SUBAK (irrigation) system.

For this purpose, a mathematical model can be used and the hydraulic performance of the system can be checked by using the St. Venant equation (Suryadi, 2007). These equations, which are the mathematical translation of the laws of conservation of mass and of momentum as follows:

$$\frac{\partial B}{\partial t} + \frac{\partial Q}{\partial x} = 0 \tag{2}$$

And

$$\frac{\partial Q}{\partial t} + gA\frac{\partial H}{\partial z} + \frac{\partial(\alpha Q v)}{\partial x} + \frac{g|Q|Q}{C^2 AR} = a\gamma w^2 \cos(\Phi - \phi) \tag{3}$$

With relation:

$$Q = v.A \tag{4}$$

Where:

t	time (s)
x	distance as measured along the channel axis (m)
H (x, t)	water level with respect to reference level (m)
v (x, t)	mean velocity (averaged over the cross-sectional area) (m/s)
Q (x, t)	discharge at location x and at time t (m^3/s)
R *(x, H)*	hydraulic radius of cross-section (m)
a (x, H)	cross-sectional flow width (m)
A (x, H)	cross-sectional flow area (m^2)
b (x, H)	cross-sectional storage width (m)
B (x, H)	cross-sectional storage area (m^2)
g	acceleration due to gravity (m/s^2)
C (x, H)	coefficient of De Chézy ($m^{1/2}/s$)
w (t)	wind velocity (m/s)
Φ (t)	wind direction in degrees (degrees)
ϕ *(x)*	direction of channel axis in degrees, measured clockwise from the north (degrees)
γ (x)	wind conversion coefficient (-)

α correction factor for non-uniformity of the velocity distribution in the advection term, defined as:

$$\alpha = \frac{A}{Q^2}\int v(y,z)^2\,dydz$$

where the integral is taken over the cross section A. (m^2)

This mass equation (1) states that if the water level changes at some location, this will be the net result of local inflow minus outflow. The momentum equation (2) expresses that the net change of momentum is the result of interior and exterior forces like friction, wind and gravity. For the derivation of these equations it has been assumed that the fluid is well mixed and hence the density may be considered to be constant. These basic equations (1) and (2) are discretized in space and time using the four point implicit Preismann scheme. Defining a section Δxi from node xi to node xi+1 and a time interval Δt from time $t = tn$ to time $t = tn$+1, the discretization of the water level H can be expressed as:

$$H_i^{n+\theta} = (1-\theta)H_i^n + \theta H_i^{n+1} \qquad (5)$$

At node x_i and time t +Δt

and

$$H^n_{i+1/2} = \frac{H^n_{i+1} + H^n_i}{2} \qquad (6)$$

in between nodes x_i and x_{i+1} at time t.

In similar way other dependent variables can be approached.

The transformed partial differential equations can be written as a system of algebraic equations by replacing the derivatives by finite difference expressions. These expressions approximate the derivatives at the point of reference ($x_{i+1/2}$, $t^{n+\theta}$) as shown in the following Figure 1.

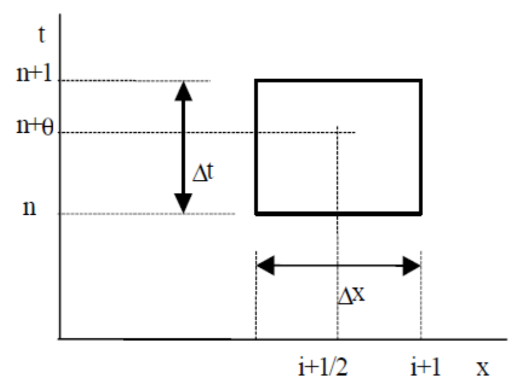

Figure 1 The Four Point Preismann scheme

Fnally, for all channel sections in the network two equations are formed which have Q and H as unknowns on the new time level t^{n+1}:

$$Q_i^{n+1} = N_{11} H_i^{n+1} + N_{12} H_{i+1}^{n+1} + N_{13} \tag{7}$$

$$Q_{i+1}^{n+1} = N_{21} H_i^{n+1} + N_{22} H_{i+1}^{n+1} + N_{23} \tag{8}$$

An example of a SUBAK system is presented below in Figure 2:

Figure 2 Subak irrigation system for upstream area in Bali

The source of irrigation water can be from river or canal and through the water management system and by applying the Subak approach water should flow reaching the agricultural field as it is planned. In the future the Subak approach could also be applied in other water management systems, i.e. lowland areas. For example, Figure 3 shows tertiary and quartenary canal system in lowland area.

Figure 3 Water management system in lowland area

The water management system is completed with water control structures for water suplly as well as for drainage purposes. It is clear that, the purpose of flow control system is to regulate water flows and water levels in the water management system to meet the delivery specifications of the agreed level of service (Melano et al, 2006). In case of drainage, the same principle can be applied in order to avoid any damage to the crops.

Based on thes layout of water management system, the model schematization can be prepared as shown in Figure 4.

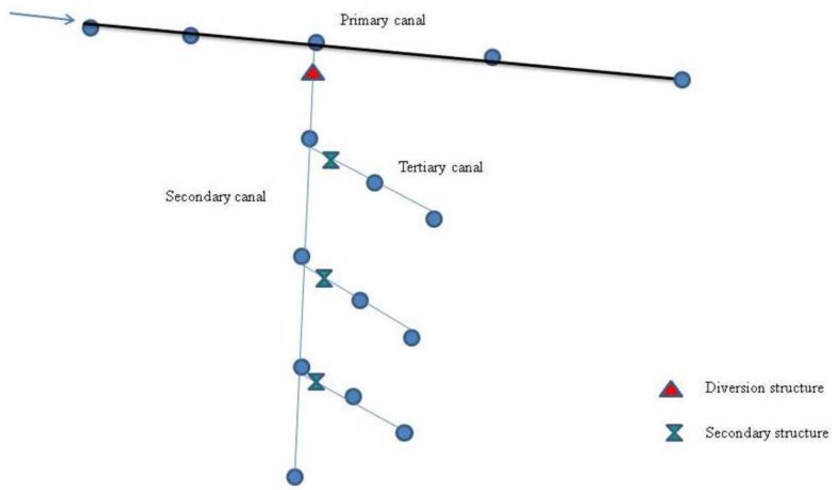

Figure 4 Subak model schematization

If the modelling is starting by the diversion structure, then the boundary condition will be the water level at that location. At the end of each tertiary canal a q-h relationship can be applied based on the tertiary canal characteristics.

Without control structure function and when the water management system simply operates as a gravity system the discharge distribution for each tertiary canal (with the same water requirement) will not be based on the water requirement. An example is shown in Figure 5.

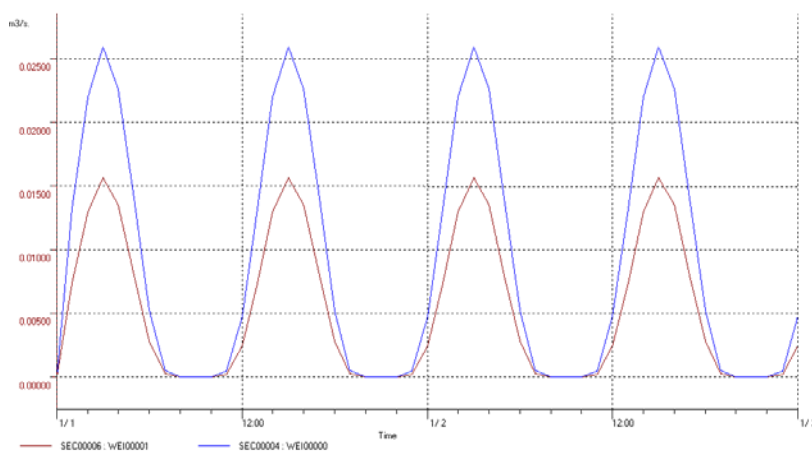

Figure 5 Water distribution for each tertiary canal

It means that for a proper water distribution, the approach as used in Subak can also be used where a proportional distribution principle is applied. In this case the width of the tertiary control structures have to be adjusted accordingly. As the result, the water distribution as presented in Figure 6 can be presented.

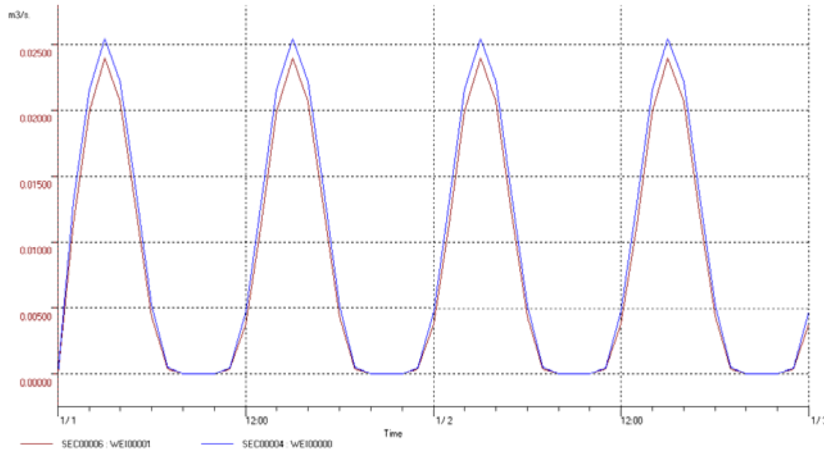

Figure 6 Water distribution by using proportional distribution principle

To translate the application of Subak approach in lowland areas especially related to the operation of water management system an example of structure control script is presented in Figure 7. In this example water level at the upstream part will be used as the reference.

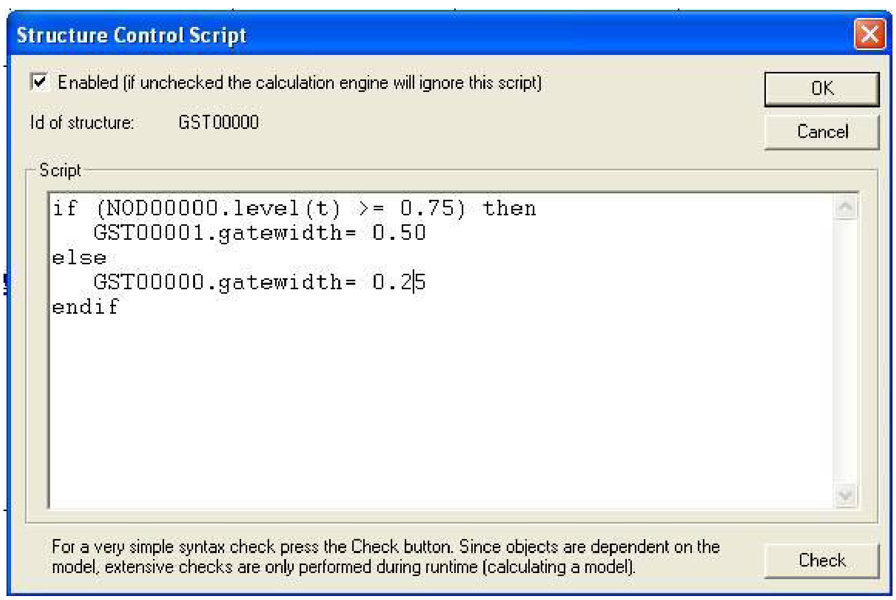

Figure 7 An example of structure control script for operation purposes

For water distribution (irrigation and drainage) several hydraulic control structures can be considered which are suitable for the local conditions. Some example of the water distribution structures are presented in Figure 8 and Figure 9. By using these control structures, water level on the field (irrigation or drainage) can be managed based on the crop water requirement.

Figure 8 Water distribution structure at the field level

Figure 9 Water control structure in order to control upstream water level

CONCLUSIONS AND RECOMMENDATIONS

In general, it can be concluded, that Subak in Bali is a unique, traditional agricultural system and has been existed for centuries and still as an impressive body in agriculture. In social activities, Subak as a cooperative specifically in farming activities. Spiritually Subak has close relation with Balinese culture. The successful of Subak is part of the successful of the agricultural production programs. In Bali, term of Subak has been used for dry/upland farming, and they called ”Subak Abian” (abian means plantation in Balinese language). Both Subaks took important part in increasing farm production in rice/wet field and in dry/upland.

Besides of the successful of the Subaks, improvements required to be done to make the Subaks better and increasing the quality scientifically. For this research in the field at multi-locations and vary in climate should be done.

It is clear that in order to have a successful water management system as Subak, an active farmer organizations will absolutely needed. In this organization a leader will be needed who lead and coordinate all the member/farmers in establishing a good water management system completed with all the related tasks. An example of field discussion under the leadership of the chairman of the organization is presented in Figure 10.

Figure 10 Field discussions among the farmers

The application of the Subak approach for water management system in lowland areas can be done by preparing a proper operation procedure for the system. This operation procedure can be derived by using a mathematical model for example DUFLOW model as a supporting tool. It can be concluded that the Subak approach can also be applied for the operation and maintenance of future water management systems in upland as well as lowland areas. But, a proper routine has to be developed inside DUFLOW in order to be able to simulate a proper water distribution based on the Subak approach. In this case, the DUFLOW model has to be run by activating structure control function.

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