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Title	CLOSED SUBMANIFOLDS WITH CONSTANT v -TH MEAN CURVATURE RELATED WITH A VECTOR FIELD IN A RIEMANNIAN MANIFOLD
Author(s)	Katsurada, Yoshie
Citation	Journal of the Faculty of Science Hokkaido University. Ser. 1 Mathematics, 20(4), 171-181
Issue Date	1969
Doc URL	https://hdl.handle.net/2115/56085
Type	departmental bulletin paper
File Information	JFSHIU_20_N4_171-181.pdf

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CLOSED SUBMANIFOLDS WITH CONSTANT ν-TH MEAN CURVATURE RELATED WITH A VECTOR FIELD IN A RIEMANNIAN MANIFOLD

By

Yoshie KATSURADA

Introduction. H. Liebmann (1900) [1][1], proved the following theorem: The only ovaloids with constant mean curvature H in an Euclidean space E^3 are the spheres.

Extension of this theorem to a convex hypersurface in an n-dimensional Euclidean space E^n has been given by W. Süss (1929) [2], (cf. also [3], p. 118, and [4]). Then H. Hope (1951) [5], and A. D. Alexandrov (1958) [6], have shown the results that the convexity is not necessary for the validity of the Liebmann–Süss theorem.

Recently the analogous problem for closed hypersurfaces in an n-dimensional Riemannian manifold R^n has been discussed by the present author [8], [9], [10], A. D. Alexandrov [7], K. Yano [13], T. Ôtsuki [15], M. Tani [16], and K. Nomizu [17], [18]. And also for a submanifold of codimension 2 in an odd dimensional sphere, M. Okumura has treated the analogue [19].

In the previous papers [11], [12], which are common works by T. Nagai, H. Kôjyo and the present author, we have given a certain extension of this problem to an m-dimensional closed submanifold V^m $(1 \leqq m \leqq n-1)$ in the n-dimensional Riemannian manifold R^n admitting a vector field ξ. However we have given there a restriction such that at each point on V^m, the vector ξ lies in the vector space spanned by the tangent space of V^m and the Euler–Schouten vector $\underset{E}{n}$.

The purpose of this paper is to give more general results except this restriction.

§ 1. Some integral formulas for a submanifold. We suppose an n-dimensional Riemannian manifold R^n $(n \geqq 3)$ of class C^r $(r \geqq 3)$ wich admits an one-parameter continuous group G of transformations generated by an infinitesimal transformation

$$\bar{x}^i = x^i + \xi^i(x)\delta\tau \tag{1.1}$$

1) Numbers in brackets refer to the references at the end of the paper.

(where x^i are local coordinates in R^n and ξ^i are the components of a contravariant vector ξ). If ξ is a Killing vector, a homothetic Killing vector, a conformal Killing vector, etc. ([14], p. 32), then the group G is called isometric, homothetic, conformal, etc.

In R^n, we consider a domain M. If the domain M is simply covered by the orbits of the transformations generated by ξ, and ξ is everywhere of class C^r and $\neq 0$ in M; then we call M a regular domain with respect to the vector field ξ.

Let us denote by V^m an m-dimensional closed orientable submanifold of class C^3 imbedded in a regular domain M with respect to the vector field ξ, locally given by

$$x^i = x^i(u^\alpha) \qquad \begin{matrix} i = 1, \cdots, n \\ \alpha = 1, \cdots, m, \end{matrix} \tag{1.2}$$

where u^α are local coordinates of V^m. Throughout the present paper Latin indices run from 1 to n and Greek indices from 1 to m. We assume that at any point on V^m the vector ξ is not on its tangent space.

We shall indicate by $\underset{p}{n}{}^i$ $(p=m+1, \cdots, n)$ the contravariant unit vectors normal V^m and suppose that they are mutually orthogonal. Let $\underset{\xi}{n}$ be in the vector space spanned by $m+1$ independent vectors $\dfrac{\partial x^i}{\partial u^\alpha}$ $(\alpha=1, \cdots, m)$ and ξ and be the unit vector normal V^m. Then, we may consider $\underset{\xi}{n}$ as one of the unit normal vectors of V^m, that is, $n^i_{m+1} = n^i_{\xi}$.

Let us consider a differential form of $m-1$ degree at a point of V^m, defined by

$$\begin{aligned} ((\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, \underbrace{dx, \cdots, dx}_{m-1})) &\overset{\text{def.}}{=} \sqrt{g}\,(\underset{\xi}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx) \\ &= \sqrt{g}\left(\underset{\xi}{n}, \cdots, \underset{n}{n}, \xi, \frac{\partial x}{\partial u^{\alpha_1}}, \cdots, \frac{\partial x}{\partial u^{\alpha_{m-1}}}\right) du^{\alpha_1} \wedge \cdots \wedge du^{\alpha_{m-1}}, \end{aligned} \tag{1.3}$$

where the symbol ( ) means a determinant of order n whose colums are the components of respective vectors, dx is a displacement along V^m, g is the determinant of the metric tensor g_{ij} of R^n. Then the exterior differential of the differential form (1.3) divided by $m!$ becomes as follows

$$\begin{aligned} \frac{1}{m!} d\,((\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx)) &= \frac{1}{m!}\{((\delta\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx)) \\ &+ ((\underset{\xi}{n}, \delta\underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx)) + \cdots \\ &+ ((\underset{\xi}{n}, \cdots, \underset{n-1}{n}, \delta\underset{n}{n}, \xi, dx, \cdots, dx)) + ((\underset{\xi}{n}, \cdots, \underset{n}{n}, \delta\xi, dx, \cdots, dx))\} \end{aligned} \tag{1.4}$$

where δv means $v_{;\alpha}\,du^{\alpha}$ and the symbol " ; " the operation of D-symbol due to van der Waerden–Bortolotti ([20] p. 254).

Let C^{i}_{j} be $\sum_{p=m+1}^{n} n^{i}_{p} n_{j}$ $(n=n)$ and $\underset{\lambda}{i}$ $(\lambda=1,\cdots,m)$ mutually orthogonal unit tangent vectors of V^{m}. Then we have

$$n^{i}_{p;\alpha} = C^{i}_{j;k} n^{j}_{p} \frac{\partial x^{k}}{\partial u^{\alpha}} = -\sum_{\lambda=1}^{m} \left(i_{\lambda\, j;k} n^{j}_{p} \frac{\partial x^{k}}{\partial u^{\alpha}} \right) i^{i}_{\lambda} .$$

Therefore we may put

$$n^{i}_{p;\alpha} = \gamma^{\gamma}_{p\,\alpha} \frac{\partial x^{i}}{\partial u^{\gamma}} .$$

Since we have

$$g_{ij}\left(\frac{\partial x^{i}}{\partial u^{\beta}}\right)_{;\alpha} n^{j}_{p} = -g_{ij} \frac{\partial x^{i}}{\partial u^{\beta}} n^{j}_{p\,\alpha} ,$$

we obtain

$$n^{i}_{p;\alpha} = -b^{\gamma}_{p\,\alpha} \frac{\partial x^{i}}{\partial u^{\gamma}} \qquad (p=\xi,\ m+2,\cdots,n) \tag{1.5}$$

where $b^{\gamma}_{p\,\alpha}$ means $g^{\gamma\beta} b_{p\,\alpha\beta}$ and $b_{p\,\alpha\beta} \equiv \left(\frac{\partial x^{i}}{\partial u^{\alpha}}\right)_{;\beta} n_{p\,i}$, and $g^{\gamma\beta}$ is the contravariant metric tensor of V^{m}.

From (1.5) the first term of the right-hand member of (1.4) becomes

$$\frac{1}{m!}((\delta n_{\xi}, n_{m+2}, \cdots, n_{n}, \xi, dx, \cdots, dx)) = (-1)^{(n-m)(n-1)} H_{1}\, n_{\xi\, i} \xi^{i} dA , \tag{1.6}$$

where dA is the area element of V^{m} and H_{1} means the first mean curvature of V^{m} with respect to the normal direction n^{i}_{ξ}. Similarly, for every integer p satisfying $m+2 \leqq p \leqq n$ we have

$$\frac{1}{m!}((n_{\xi}, \cdots, \delta n_{p}, \cdots, n_{n}, \xi, dx, \cdots, dx)) = (-1)^{(n-m)(n-1)} H_{1}\, n_{p\, i} \xi^{i} dA . \tag{1.7}$$
$$= 0$$

because ξ lies in the vector space spanned by $m+1$ independent vectors $\frac{\partial x^{i}}{\partial u^{\alpha}}$ $(\alpha=1,\cdots,m)$ and n_{ξ}.

On the other hand the last term of the right-hand member of 1.4 becomes

$$\frac{1}{m!}((n_{\xi}, \cdots, n_{n}, \delta\xi, dx, \cdots, dx))$$
$$= (-1)^{(n-m)(n-1)} \frac{1}{2m} (L_{\xi}\, g_{ij}) \frac{\partial x^{i}}{\partial u^{\alpha}} \frac{\partial x^{j}}{\partial u^{\beta}} g^{\alpha\beta} dA , \tag{1.8}$$

where $\underset{\xi}{L}\, g_{ij}$ is the Lie derivative of g_{ij} with respect to ξ ([14], p. 5).

From (1. 6), (1. 7) and (1. 8), (1. 4) is rewritten as follows

$$\frac{1}{m!}d((\underset{\xi}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx)) = (-1)^{(n-m)(n-1)}\left\{H_1 \underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}(\underset{\xi}{L}\, g_{ij})\frac{\partial x^i}{\partial u^\alpha}\frac{\partial x^j}{\partial u^\beta}g^{\alpha\beta}dA\right\}. \tag{1.9}$$

Integrating both members of (1. 9) over the whole submanifold and applying Stokes' theorem, we obtain

$$\frac{1}{m!}\int_{\partial V^m}((\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, dx, \cdots, dx)) = (-1)^{(n-m)(n-1)}\left\{\int_{V^m} H_1 \underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}\int_{V^m} g^{*ij}\underset{\xi}{L}\, g_{ij}dA\right\},$$

where ∂V^m means the boundary of V^m and g^{*ij} is $\dfrac{\partial x^i}{\partial u^\alpha}\dfrac{\partial x^j}{\partial u^\beta}g^{\alpha\beta}$. Making use of the fact that V^m is closed, we have

$$\int_{V^m} H_1 \underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}\int_{V^m} g^{*ij}\underset{\xi}{L}\, g_{ij}dA = 0. \tag{I''}$$

If the manifold R^n assumes of constant Riemann curvature which includes an Euclidean space, then we consider the following differential form of $m-1$ degree

$$\begin{aligned}&((\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, \underbrace{\underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}}_{\nu}, \underbrace{dx, \cdots, dx}_{m-\nu-1}))\\ &\overset{\text{def.}}{=} \sqrt{g}\,(\underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \xi, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx)\end{aligned} \tag{1.10}$$

for a fixed integer ν satisfying $m-1 \geqq \nu \geqq 1$.

As well-known, a submanifold V^m in R^n has the following property:

$$\underset{\xi}{b}_{\alpha\beta;\gamma} - \underset{\xi}{b}_{\alpha\gamma;\beta} = -R_{ijkl}\underset{\xi}{n^i}\frac{\partial x^j}{\partial u^\alpha}\frac{\partial x^k}{\partial u^\beta}\frac{\partial x^l}{\partial u^\gamma} \qquad ([20], \text{ p. } 226),$$

where R_{ijkl} is the curvature tensor of R^n. Since R^n is of constant Riemann curvature, we have

$$\underset{\xi}{n^i}_{,\alpha;\beta} - \underset{\xi}{n^i}_{;\beta;\alpha} = 0. \tag{1.11}$$

Consequently differentiating exteriorly the differential form (1. 10), we have

$$
\begin{aligned}
&d((n, \underset{\xi}{n}, \underset{m+2}{\cdots}, n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) \\
&\quad = ((\delta n, \underset{\xi}{n}, \underset{m+2}{\cdots}, n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) \\
&\quad\quad + ((n, \underset{\xi}{\delta n}, \underset{m+2}{\cdots}, n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) \\
&\quad\quad + \cdots + ((n, \underset{\xi}{n}, \underset{m+2}{\cdots}, \delta n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) \\
&\quad\quad + ((n, \underset{\xi}{n}, \underset{m+2}{\cdots}, n, \underset{u}{\delta\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)),
\end{aligned} \tag{1.12}
$$

because $((n, \underset{\xi}{n}, \underset{m+2}{\cdots}, n, \underset{n}{\xi}, \delta\delta n, \underset{\xi}{\delta n}, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx))=0$ from (1.11).

On substituting $\underset{\xi}{n}^{i}_{;\alpha} = -\underset{\xi}{b}^{\beta}_{\alpha}\dfrac{\partial x^{i}}{\partial u^{\beta}}$ into the first term of the right-hand member of (1.12), we get

$$
\begin{aligned}
&((\delta n, \underset{\xi}{n}, \underset{m+2}{\cdots}, n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) \\
&\quad = m!(-1)^{(n-m)(n-1)-\nu}\underset{\xi}{H}_{\nu+1}n_{i}\xi^{i}dA\,,
\end{aligned} \tag{1.13}
$$

where $\underset{\xi}{H}_{\nu+1}$ denotes the $\nu+1$-th mean curvature of V^{m} with respect to the normal direction $\underset{\xi}{n}^{i}$ and if we indicate by $\underset{\xi}{k}_{1}, \underset{\xi}{k}_{2}, \cdots, \underset{\xi}{k}_{m}$ the principal curvatures of V^{m} for the normal vector $\underset{\xi}{n}$, $\underset{\xi}{H}_{\nu+1}$ is defined to be the $\nu+1$-th elementary symmetric function of $\underset{\xi}{k}_{\alpha}$ $(\alpha=1, \cdots, m)$ divided by the number of terms, that is,

$$
\binom{m}{\nu+1}\underset{\xi}{H}_{\nu+1} = \sum_{\alpha_1<\alpha_2<\cdots<\alpha_{\nu+1}} \underset{\xi}{k}_{\alpha_1}\underset{\xi}{k}_{\alpha_2}\cdots\underset{\xi}{k}_{\alpha_{\nu+1}}\,.
$$

Also, by virtue of (1.5) we can see that the vectors

$$
\underset{\xi}{n}\times\underset{m+2}{\delta n}\times\underset{m+3}{n}\times\cdots\times\underset{n}{n}\times\underbrace{\underset{\xi}{\delta n}\times\cdots\times\underset{\xi}{\delta n}}_{\nu}\times\underbrace{dx\times\cdots\times dx}_{m-\nu-1},
$$

$$
\underset{\xi}{n}\times\underset{m+2}{n}\times\underset{m+3}{\delta n}\times\cdots\times\underset{n}{n}\times\underset{\xi}{\delta n}\times\cdots\times\underset{\xi}{\delta n}\times dx\times\cdots\times dx\,,
$$

$\cdots$

and

$$
\underset{\xi}{n}\times\underset{m+2}{n}\times\cdots\times\underset{n-1}{n}\times\delta n\times\underset{n}{\delta n}\times\underset{\xi}{\cdots}\times\delta n\times dx\times\cdots\times dx
$$

have the same direction to the covariant vectors $\underset{m+2}{n}, \underset{m+3}{n}, \cdots$ and $\underset{n}{n}$ respectively. Thus we obtain

$$
((n, \underset{\xi}{\delta n}, \underset{m+2}{n}, \underset{m+3}{n}, \cdots, n, \underset{n}{\xi}, \delta n, \underset{\xi}{\cdots}, \delta n, dx, \cdots, dx)) = 0\,,
$$

$$
\begin{aligned}
&((\underset{\xi}{n}, \underset{\xi}{n}, \underset{m+2}{n}, \underset{m+3}{\delta n}, \cdots, \underset{n}{n}, \underset{\xi}{\xi}, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx)) = 0\,,\\
&\qquad\qquad \cdots\,,\\
&((\underset{\xi}{n}, \underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n-1}{n}, \underset{n}{\delta n}, \underset{\xi}{\xi}, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx)) = 0\,,
\end{aligned}
\tag{1.14}
$$

because ξ lies in the vector space spanned by $m+1$ independent vectors $\dfrac{\partial x^i}{\partial u^\alpha}$ $(\alpha=1, \cdots, m)$ and $\underset{\xi}{n}$.

From that the vector $\underset{\xi}{n}\times\underset{m+2}{n}\times\cdots\times\underset{n}{n}\times\underset{\xi}{\delta n}\times\cdots\times\underset{\xi}{\delta n}\times dx\times\cdots\times dx$ is orthogonal to the normal vectors $\underset{\xi}{n}, \underset{m+2}{n}, \cdots$ and $\underset{n}{n}$, and $\underset{\xi}{\delta n^i} = -\underset{\xi}{b_\alpha^\beta}\dfrac{\partial x^i}{\partial u^\beta}du^\alpha$, the last term of the right-hand member of (1.12) becomes as follows

$$
\begin{aligned}
&((\underset{\xi}{n}, \underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \underset{\xi}{\delta\xi}, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx))\\
&\qquad = m!(-1)^{(n-m)(n-1)-\nu}\frac{1}{2m}\underset{\xi}{H_\nu^{\alpha\beta}}\underset{\xi}{L g_{\alpha\beta}}dA\,,
\end{aligned}
\tag{1.15}
$$

where $\underset{\xi}{L g_{\alpha\beta}} = (\underset{\xi}{L g_{ij}})\dfrac{\partial x^i}{\partial u^\alpha}\dfrac{\partial x^j}{\partial u^\beta}$ and

$$
\underset{\xi}{H_\nu^{\alpha\beta}} = \frac{1}{(m-1)!}\varepsilon^{\alpha\alpha_1\cdots\alpha_{m-1}}\varepsilon^{\beta\beta_1\cdots\beta_{m-1}}\underset{\xi}{b_{\alpha_1\beta_1}}\cdots\underset{\xi}{b_{\alpha_\nu\beta_\nu}}g_{\alpha_{\nu+1}\beta_{\nu+1}}\cdots g_{\alpha_{m-1}\beta_{m-1}}\,,
$$

and $\varepsilon^{\alpha\alpha_1\cdots\alpha_{m-1}}$ denotes the ε-symbol of the submanifold V^m. Accordingly we have

$$
\begin{aligned}
&\frac{1}{m!}d((\underset{\xi}{n}, \underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \underset{\xi}{\xi}, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx))\\
&\qquad = (-1)^{(n-m)(n-1)-\nu}\left\{\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}\underset{\xi}{H_\nu^{\alpha\beta}}\underset{\xi}{L g_{\alpha\beta}}dA\right\}.
\end{aligned}
\tag{1.16}
$$

Integrating both members of (1.16) over the whole submanifold V^m and applying Stokes' theorem, we have

$$
\begin{aligned}
&\frac{1}{m!}\int_{\partial V^m}((\underset{\xi}{n}, \underset{\xi}{n}, \underset{m+2}{n}, \cdots, \underset{n}{n}, \underset{\xi}{\xi}, \underset{\xi}{\delta n}, \cdots, \underset{\xi}{\delta n}, dx, \cdots, dx))\\
&\qquad = (-1)^{(n-m)(n-1)-\nu}\left\{\int_{V^m}\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}\int_{V^m}\underset{\xi}{H_\nu^{\alpha\beta}}\underset{\xi}{L g_{\alpha\beta}}dA\right\}.
\end{aligned}
$$

Thus, for a closed orientable submanifold V^m we obtain

$$
\text{(II}'')\qquad \int_{V^m}\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA + \frac{1}{2m}\int_{V^m}\underset{\xi}{H_\nu^{\alpha\beta}}\underset{\xi}{L g_{\alpha\beta}}dA = 0\,.
$$

If $m=n-1$, that is, V^m is the hypersurface in R^n, the formulas (I'') and

(II″) are coincide with the formulas (I) and (II) given in the previous paper [8]. Especially if the vector $\underset{\xi}{n}$ is coincide with the Euler-Schouten unit vector $\underset{E}{n}$ at each point on V^m, then the formulas (I″) and (II″) become the formulas (I′) and (II′) given in the previous paper [12].

§ 2. The integral formulas concerning some special transformations. In this section, we shall discuss the formulas (I″) and (II″) for a special infinitesimal transformation. Let the group G of transformations be conformal, that is, ξ^i satisfies an equation: $\underset{\xi}{L}g_{ij}\equiv\xi_{i;j}+\xi_{j;i}=2\phi g_{ij}$ ([14], p. 32). Then we obtain

$$g^{*ij}\underset{\xi}{L}g_{ij}=2m\phi\,,\qquad \underset{\xi}{H_\nu^{\alpha\beta}}\underset{\xi}{L}g_{\alpha\beta}=2m\phi\underset{\xi}{H_\nu}\,.$$

Therefore (I″) and (II″) are rewritten in the following forms:

$$(\mathrm{I}'')_{\mathrm{c}}\qquad \int_{V^m}\underset{\xi}{H_1}\underset{\xi}{n_i}\xi^i dA+\int_{V^m}\phi dA=0\,,$$

$$(\mathrm{II}'')_{\mathrm{c}}\qquad \int_{V^m}\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA+\int_{V^m}\phi\underset{\xi}{H_\nu}dA=0\qquad (1\leqq\nu\leqq m-1)$$

and we can see

$$(\mathrm{I}'')_{\mathrm{h}}\qquad \int_{V^m}\underset{\xi}{H_1}\underset{\xi}{n_i}\xi^i dA+c\int_{V^m}dA=0\,,$$

$$(\mathrm{II}'')_{\mathrm{h}}\qquad \int_{V^m}\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA+c\int_{V^m}\underset{\xi}{H_\nu}dA=0\qquad (1\leqq\nu\leqq m-1)^{2)}$$

in case of $\phi=$constant $(\equiv c)$ (G being homothetic), and

$$(\mathrm{I}'')_{\mathrm{i}}\qquad \int_{V^m}\underset{\xi}{H_1}\underset{\xi}{n_i}\xi^i dA=0\,,$$

$$(\mathrm{II}'')_{\mathrm{i}}\qquad \int_{V^m}\underset{\xi}{H_{\nu+1}}\underset{\xi}{n_i}\xi^i dA=0\qquad (1\leqq\nu\leqq m-1)$$

in case of $\phi=0$ (G being isometric).

Especially if our manifold R^n is an Euclidean space E^n and if ξ is the homothetic Killing vector field on E^n with components $\xi^i=x^i$, x^i being rectangular coordinates with a point in the interior of V^m as origin in the space E^n, then the orbits of the transformations generated by ξ are the lines through

2) In this case, R^n becomes an Euclidean space, because if R^n with constant Riemann curvature admits an one-parameter group G of homothetic transformations, then either R^n is E^n or the group G is isometric.

the origin and we have

$$\underset{\xi}{L} g_{ij} = 2g_{ij} .$$

Consequently, from $(I'')_h$ and $(II'')_h$ we obtain

$$\text{(I*)} \qquad \int_{V^m} \underset{\xi}{H_1} p dA + \int_{V^m} dA = 0 ,$$

$$\text{(II*)} \qquad \int_{V^m} \underset{\xi}{H_{\nu+1}} p dA + \int_{V^m} \underset{\xi}{H_\nu} dA = 0 ,$$

where $p = \underset{\xi}{n_i} x^i$. This means that the formulas (I*) and (II*) are generalization of those formulas given by C. C. Hsiung [4] for a closed orientable hypersurface in an n-dimensional Euclidean space E^n.

§ 3. Some properties of a closed orientable submanifold related with a vector field. In this section we suppose again that the group G is conformal. Then we shall prove the following four theorems for a closed orientable submanifold V^m in a Riemannian manifold R^n with constant Riemann curvature.

Theorem 3.1. *If in R^n, there exists such a group G of conformal transformations as ρ is positive (or negative) at each point of V^m and if $\underset{\xi}{H_1}$ is constant, then every point of V^m is umbilic with respect to the normal vector $\underset{\xi}{n}$, where ρ denotes $\underset{\xi}{n_i}\xi^i$.*

Proof. Multiplying the formula $(I'')_c$ by $\underset{\xi}{H_1} = \text{const.}$, we have

$$\int_{V^m} \underset{\xi}{H_1^2} \rho dA + \int_{V^m} \phi \underset{\xi}{H_1} dA = 0 .$$

On the other hand, from $(II'')_c$ we have

$$\int_{V^m} \underset{\xi}{H_2} \rho dA + \int_{V^m} \phi \underset{\xi}{H_1} dA = 0 .$$

Consequently it follows that

$$\int_{V^m} (\underset{\xi}{H_1^2} - \underset{\xi}{H_2}) \rho dA = 0 .$$

From our assumption about ρ, this holds if and only if $\underset{\xi}{H_1^2} - \underset{\xi}{H_2} = 0$, since

$$\underset{\xi}{H_1^2} - \underset{\xi}{H_2} = \frac{1}{m^2(m-1)} \sum_{\alpha<\beta} (\underset{\xi}{k_\alpha} - \underset{\xi}{k_\beta})^2 \geqq 0 .$$

Therefore at each point of V^m we obtain

$$\underset{\xi}{k_1} = \underset{\xi}{k_2} = \cdots = \underset{\xi}{k_m} .$$

Accordingly every point of V^m is umbilic with respect to $\underset{\xi}{n}$.

Theorem 3.2. *If in R^n, there exists such a group G of conformal transformations as ρ is positive (or negative) at each point of V^m, and if the principal curvatures $\underset{\xi}{k_1}, \underset{\xi}{k_2}, \cdots, \underset{\xi}{k_m}$ at each point of V^m are positive and $\underset{\xi}{H_\nu}$ is constant for any ν $(1<\nu\leqq m-1)$, then every point of V^m is umbilic with respect to the normal vector $\underset{\xi}{n}$.*

Proof. Multiplying the formula $(\mathrm{I}'')_c$ by $\underset{\xi}{H_\nu}=\text{const.}$, we obtain

$$\int_{V^m} \underset{\xi}{H_1}\underset{\xi}{H_\nu}\rho dA + \int_{V^m} \phi \underset{\xi}{H_\nu} dA = 0 . \tag{3.1}$$

By vatue of $(\mathrm{II}'')_c$ and (3.1), we have

$$\int_{V^m} (\underset{\xi}{H_1}\underset{\xi}{H_\nu} - \underset{\xi}{H_{\nu+1}})\rho dA = 0 .$$

From our assumption, this holds if and only if $\underset{\xi}{H_1}\underset{\xi}{H_\nu} - \underset{\xi}{H_{\nu+1}} = 0$, since

$$\underset{\xi}{H_1}\underset{\xi}{H_\nu} - \underset{\xi}{H_{\nu+1}} = \frac{\nu!(m-\nu-1)!}{m\,m!} \sum \underset{\xi}{k_{\alpha_1}} \cdots \underset{\xi}{k_{\alpha_{\nu-1}}} (\underset{\xi}{k_{\alpha_\nu}} - \underset{\xi}{k_{\alpha_{\nu+1}}})^2 \geqq 0 .$$

Then at each point of V^m, we obtain

$$\underset{\xi}{k_1} = \underset{\xi}{k_2} = \cdots = \underset{\xi}{k_m} .$$

Accordingly every point of V^m is umbilic with respect to $\underset{\xi}{n}$.

Theorem 3.3. *If in R^n, there exists such a group G of conformal transformations as ρ is positive (or negative) at each point of V^m, for which $\underset{\xi}{H_1}\rho + \phi \geqq 0$ (or $\leqq 0$) at all points of V^m, then every point of V^m is umbilic with respect to $\underset{\xi}{n}$.*

Proof. If we express the formula $(\mathrm{I}'')_c$ as follows

$$\int_{V^m} (\underset{\xi}{H_1}\rho + \phi) dA = 0 ,$$

then from our assumption we have the relation:

$$\phi = -\underset{\xi}{H_1}\rho . \tag{3.2}$$

Substituting (3.2) into $(\mathrm{II}'')_c$ for $\nu=1$, we have

$$\int_{V^m} (H_1^2 - H_2)\rho dA = 0 .$$

Thus, we can see the conclusion.

Theorem 3.4. *If H_1 is positive (or negative) at all points of V^m and if R^n admits such a group G of conformal transformations as ϕ is positive (or negative), for which either $\rho \geqq \frac{-\phi}{H_1}$ or $\rho \leqq \frac{-\phi}{H_1}$ at all points of V^m, then every point of V^m is umbilic with respect to n.*

Proof. The formula $(I'')_c$ is rewritten as follows

$$\int_{V^m} H_1 \left(\rho + \frac{\phi}{H_1}\right) dA = 0 .$$

By virtue of our assumptions $H_1 > 0$ (or <0) and $\rho + \frac{\phi}{H_1} \geqq 0$ (or $\leqq 0$) at all points of V^m, we have the following relation

$$\rho = -\frac{\phi}{H_1} . \tag{3.3}$$

Substituting (3.3) into $(II'')_c$ for $\nu = 1$, we obtain

$$\int_{V^m} \frac{\phi}{H_1} (H_1^2 - H_2) dA = 0 ,$$

which holds if and only if $H_1^2 - H_2 = 0$. Thus we obtain the conclusion.

Remark I. If V^m is the hypersurface in R^n, these four theorems are coincide with the theorems given in the previous paper [8]. Especially if the vector n is coincide with the Euler-Schouten unit vector n at each point of V^m, then these four theorems become those theorems given in the previous paper [12].

Remark II. In all these sections we have treated the normal unit vector n with respect to the vector field ξ and the mean curvature H_ν. These are the notions due to R. E. Stong [21].

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(Received Nov. 26, 1968)